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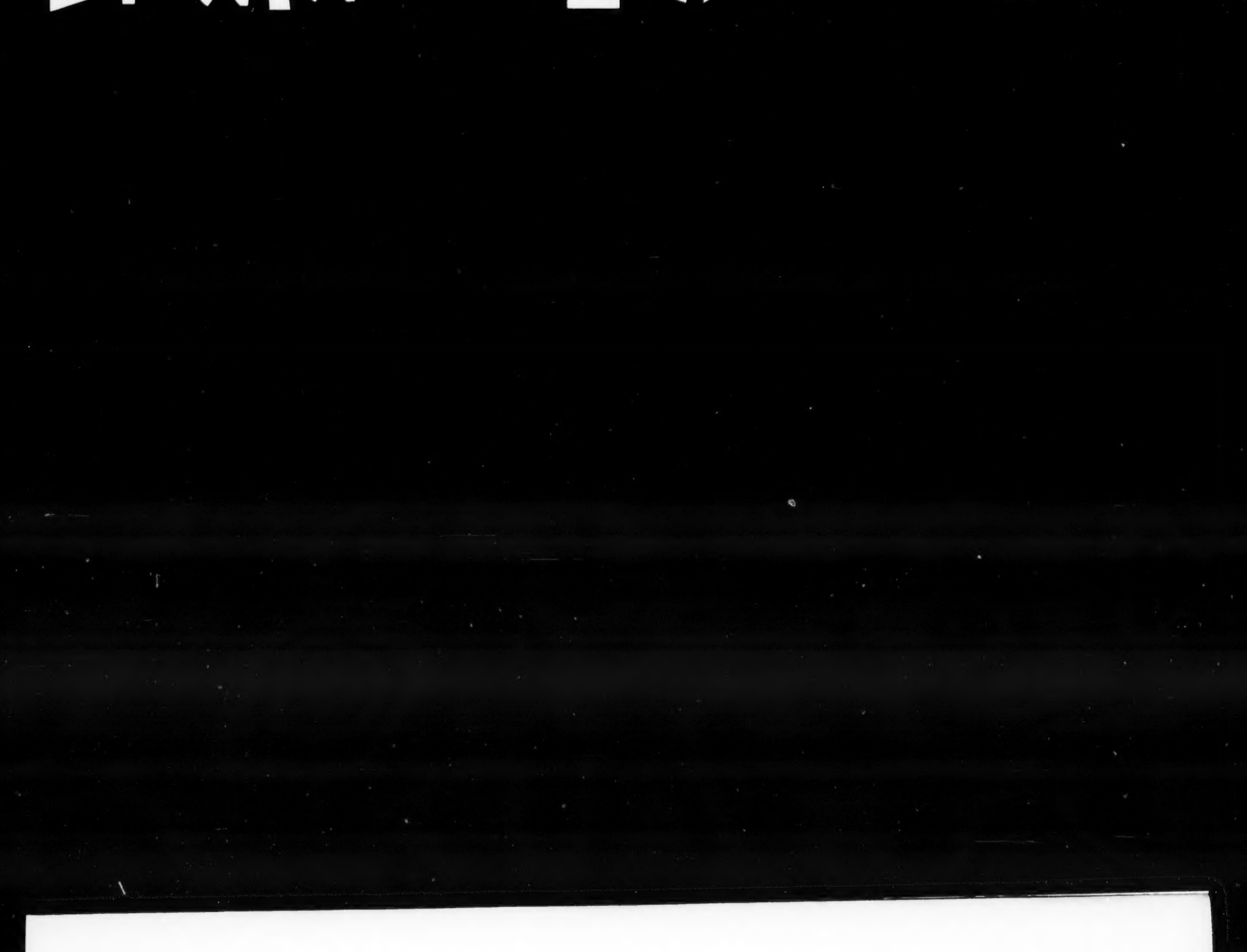

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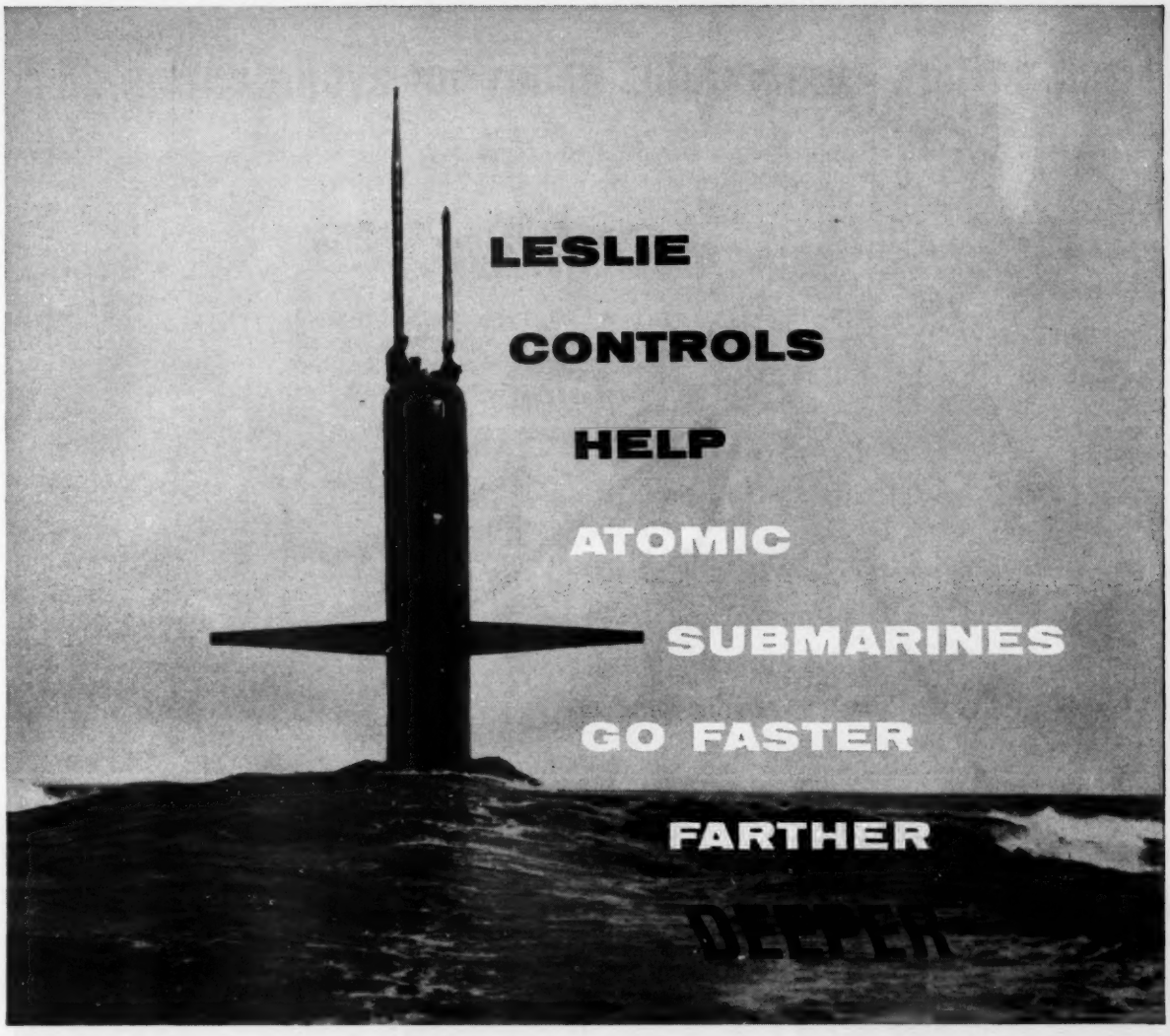

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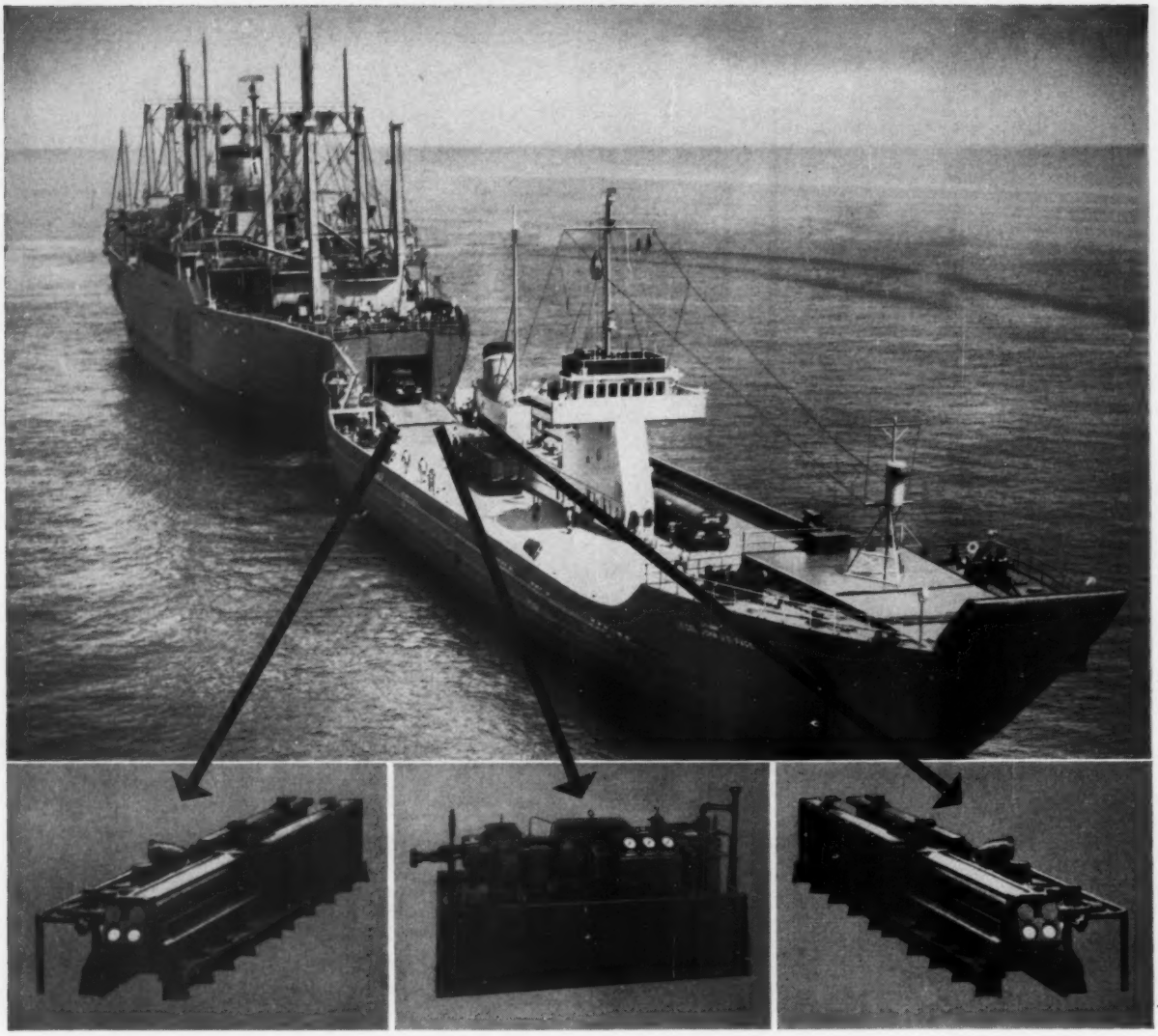

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new AE automatic tension tie stabilizes ship-to-ship transfers at sea

One of the toughest problems in military supply operations is the successful "marrying" of ships at sea for the transfer of vehicles and equipment. Such an operation was accomplished recently with the ship-to-ship transfer of cargo between the Army's Beach Discharge Lighter "*Lt. Col. John U. D. Page*" and the Navy's Roll-on Roll-off vessel "*Comet*".

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Leaded Muntz Metal-274 has good strength, stiffness and elasticity. It machines well and is the most commonly used tube-sheet metal. Leaded Muntz Metal hot rolls easily and can be manufactured in very large sizes. Many of the other tube-sheet alloys are superior to Leaded Muntz Metal in corrosion resistance and are used in preference to it for that reason. However, tube sheets are necessarily so thick that a long time elapses before they are affected by corrosion to the extent that their strength or usefulness is impaired.

Naval Brass-450 is an alloy of the same general type as Leaded Muntz Metal but includes approximately 0.75% tin in its composition. The tin content increases the alloy's resistance to corrosion, and makes it preferable to Leaded Muntz Metal, especially at higher than normal working temperatures.

Arsenical Admiralty-439 is resistant to dezincification corrosion and can be used where its higher resistance to corrosion is required, especially in process equipment.

Ambraloy-917 is available for use where strength and corrosion resistance superior to Naval Brass and Admiralty Metal are desired, as in oil-cooler tube sheets.

Cupro Nickel, 10%-755 and Cupro Nickel, 30%-702 are used extensively with tubes of similar composition in marine condensers and in process heat exchange equipment.

Baffle and Support Plates for use in oil refinery equipment are most often of Leaded Muntz Metal and Yellow Brass. For more severe applications Admiralty, Naval Brass, Cupro Nickel, Copper, or Everdur® are often used.

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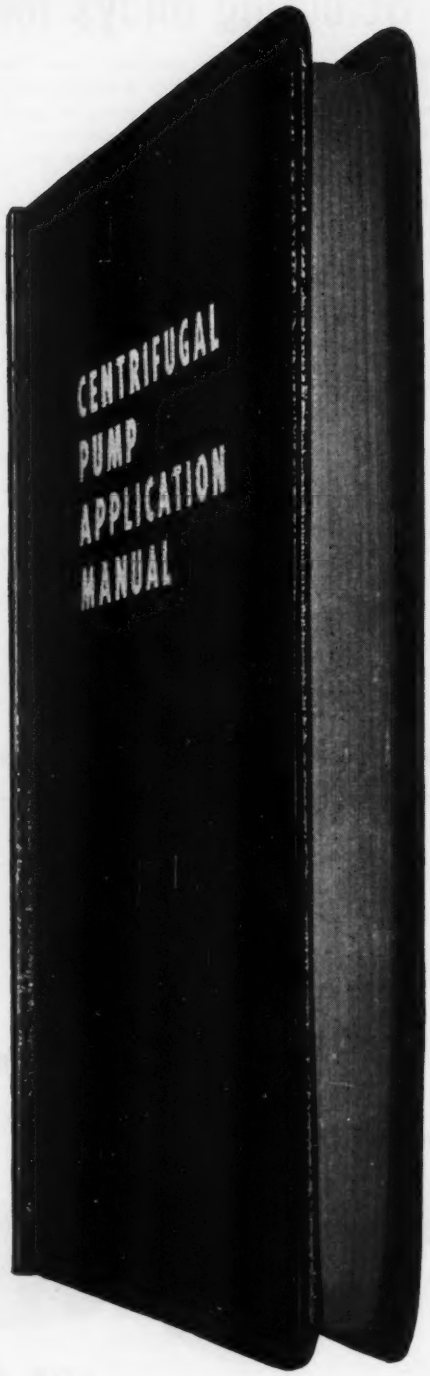

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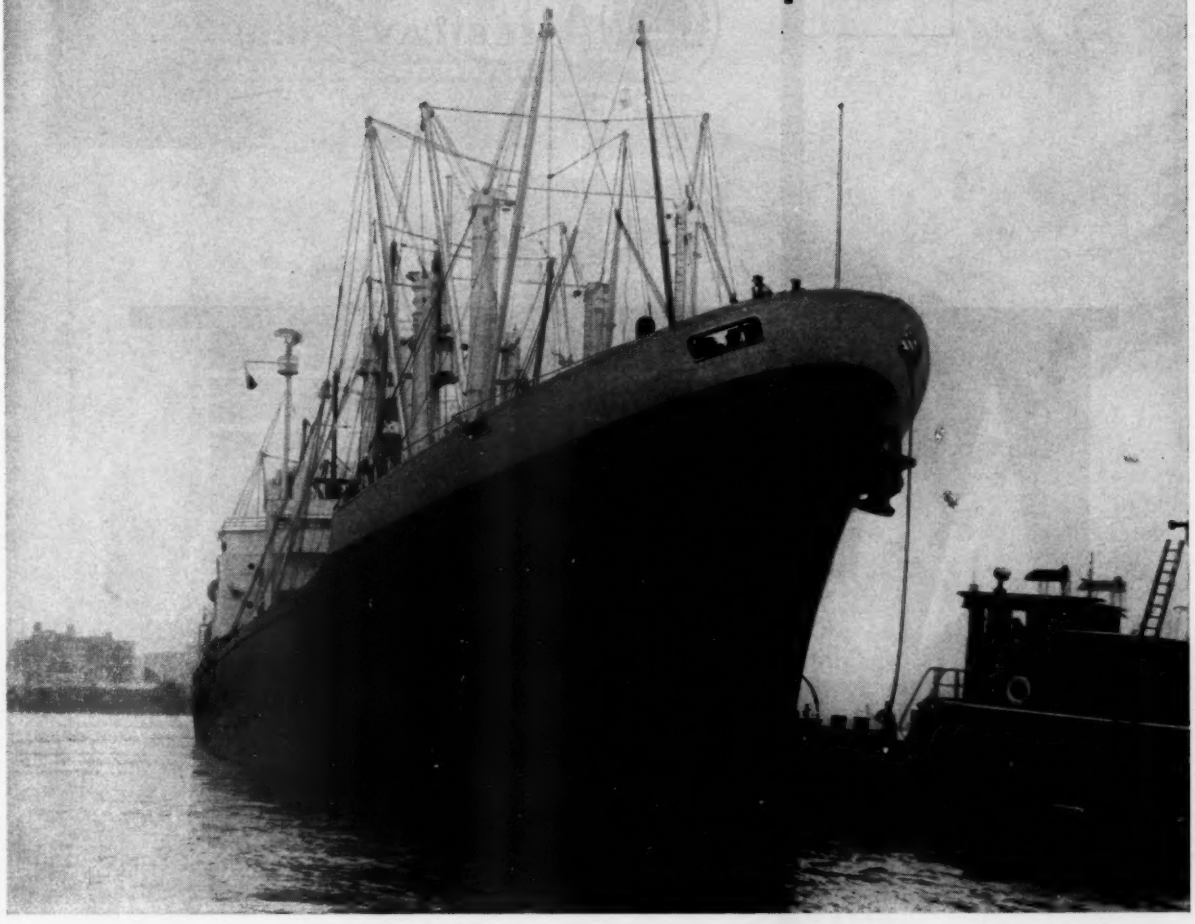
Pioneer Mart of United States Lines sets new Orient-N.Y. speed mark



Pioneer Mart, one of nine Mariner-Class vessels of The United States Lines, recently set a new speed record between Japan and New York via the Panama Canal.

Commanded by Captain John F. Wilson, the 20-knot cargo vessel covered 9,934 miles in the exceptionally fast time of nineteen days, fourteen hours and nine minutes.

Previously, the vessel set another record by making a non-stop trip from New York to Manila in 26 days.

Some remarkably fast runs have also been recorded by the Pioneers Minx, Muse, Mill and Moor, all sister ships of the Pioneer Mart in Far East service. The Pioneer Minx, for example, made the New York-Manila run in 28 days, including a stop at Charleston. *All five of these Pioneers are powered by C-E Boilers.*

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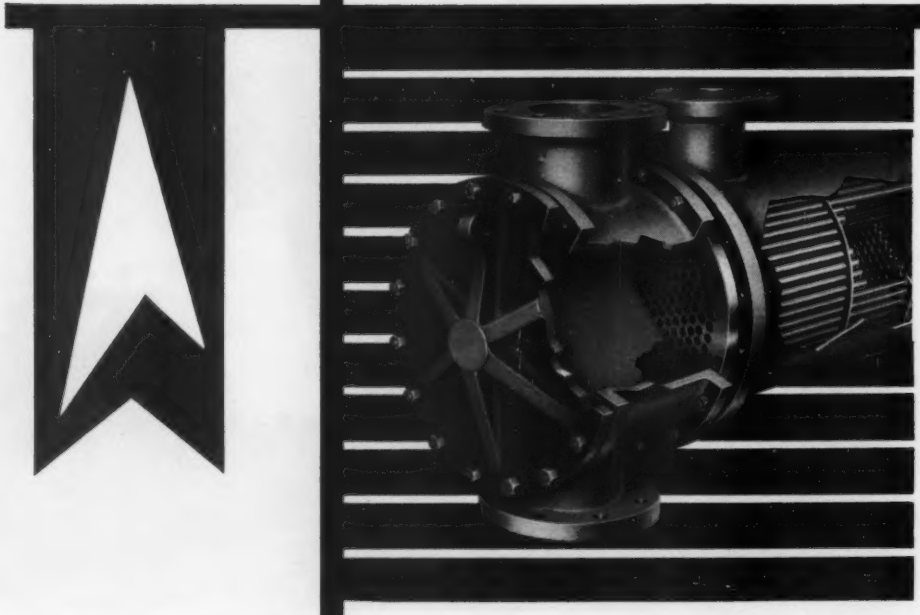

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New B&W 2-Cavity Boilers

11 fast cargo ships get boilers with dual "walk in" access to superheaters to cut cleaning costs

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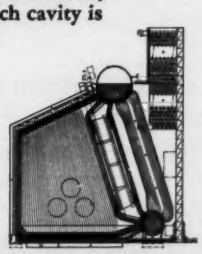
For more about B&W's new 2-Cavity Marine Boilers . . . and how they can work for *you*, at a practical cost, write The Babcock & Wilcox Company, Boiler Division, 161 East 42nd Street, New York 17, N. Y.



B&W 2-Cavity Boiler: Note *double* access spaces in superheater area for easy cleaning.

M-415

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BOILER DIVISION

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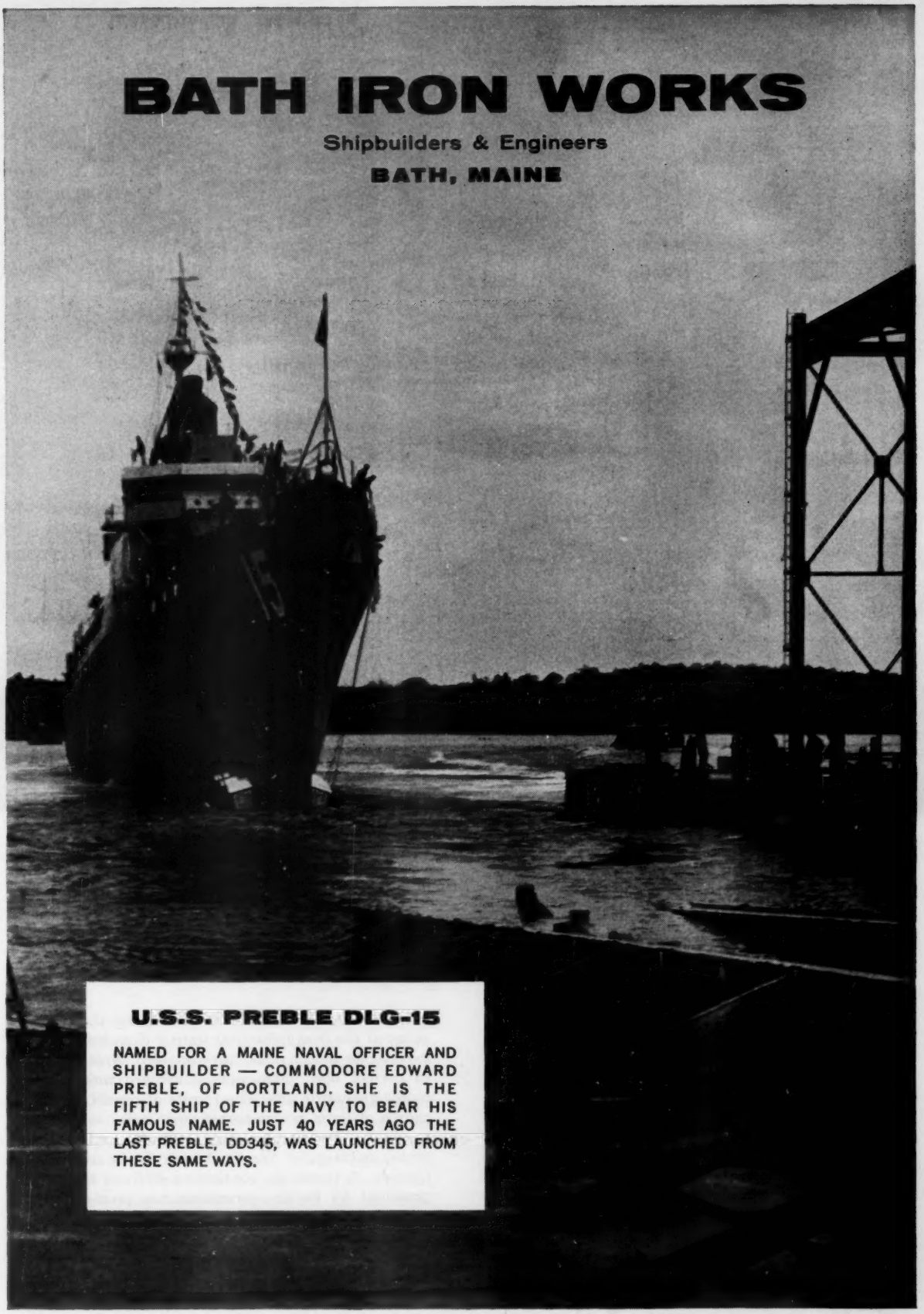

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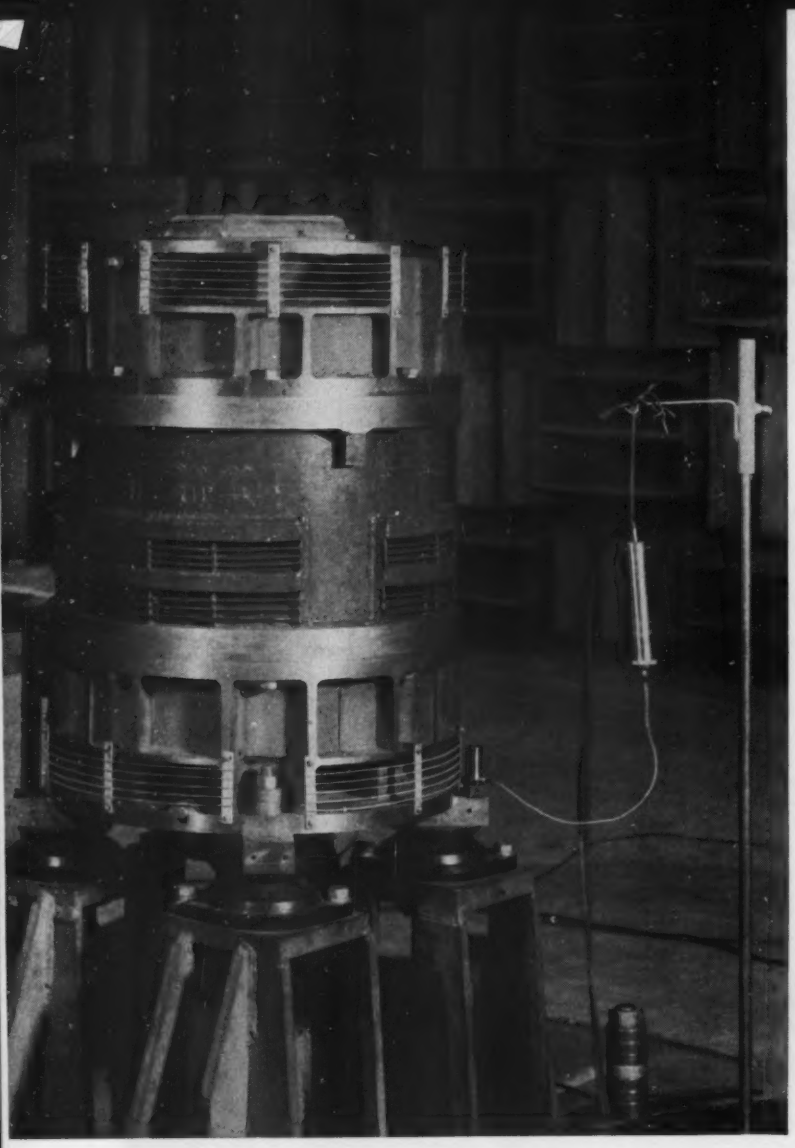
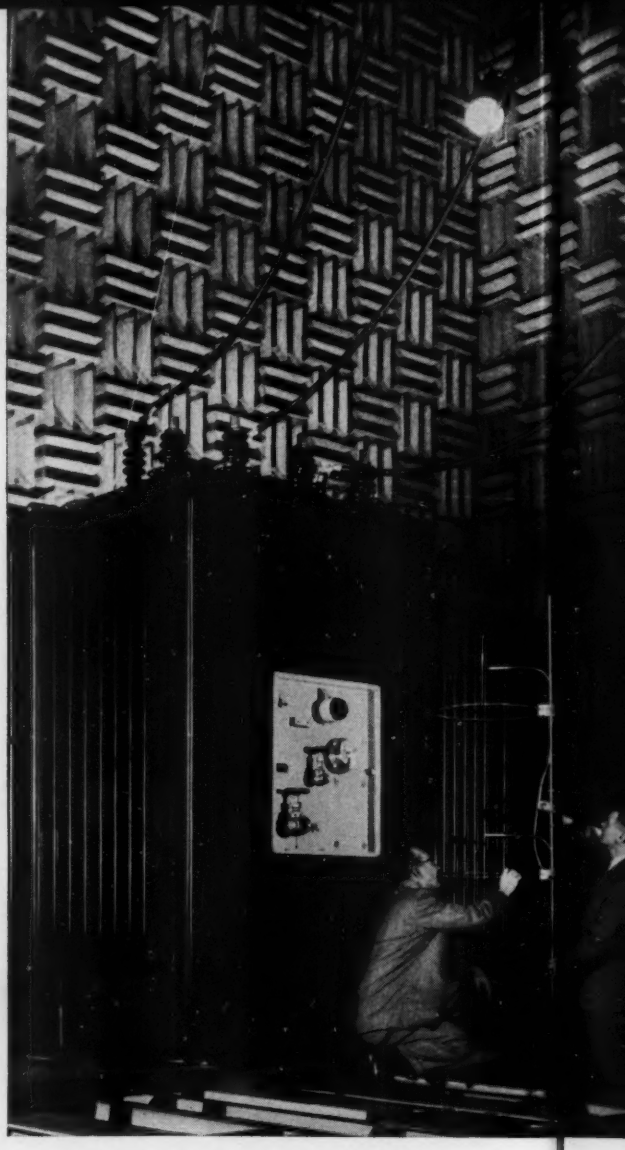


AT BUFFALO, N. Y., research on motor noise in this big sound test chamber enabled Westinghouse to design this advanced motor for use in areas of submarines where absolute quiet is required. When operating, motor sound is so small that it is measured in microinches of movement.



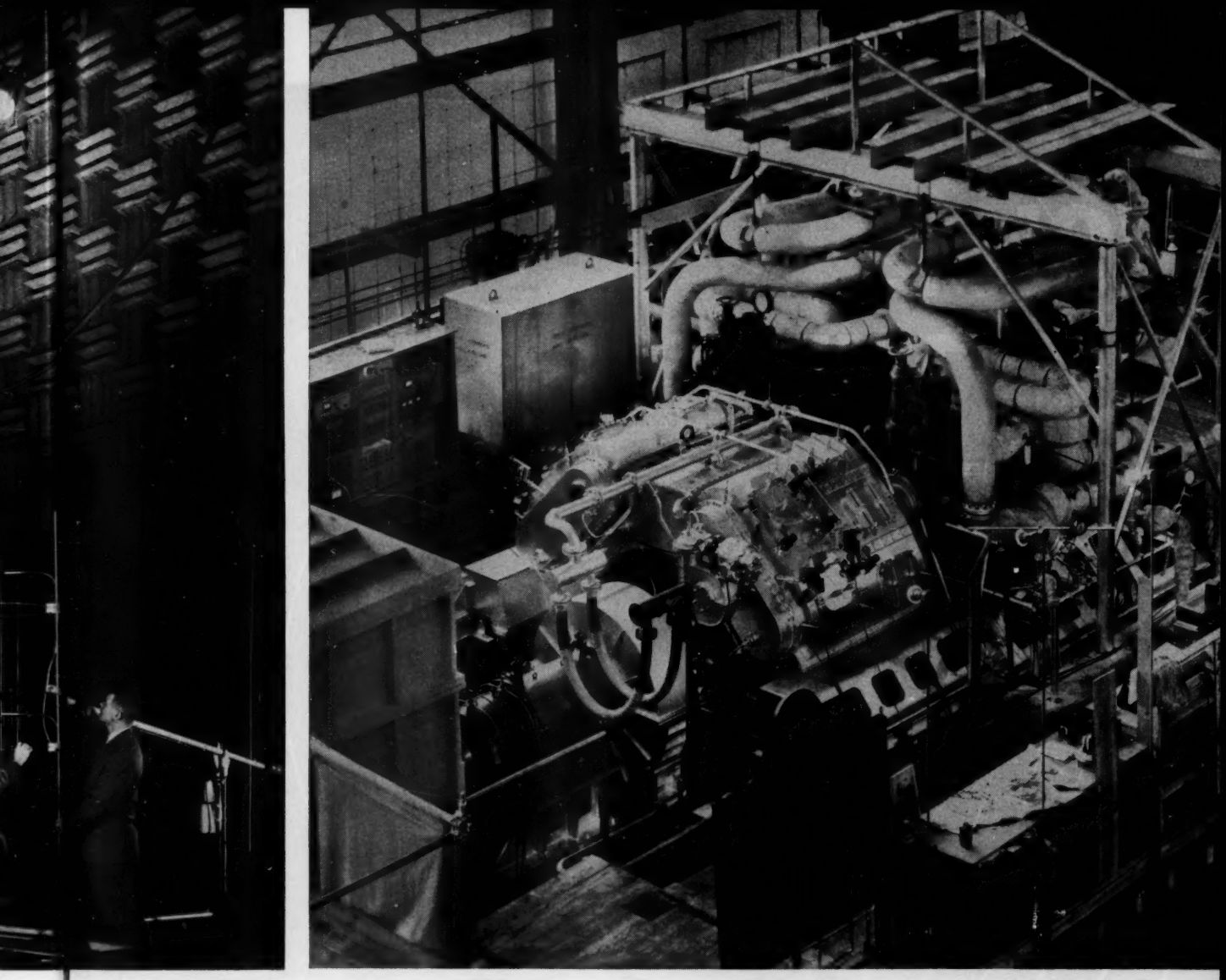
AT SHARON, PA., a huge substation transformer is readied in a 45 x 58 x 50' room—called an anechoic chamber—for noise measurement operations. Such tests, conducted for the past several years, have produced notable reductions in the sound levels of small shipboard transformers.

Westinghouse research and manufacturing

During 15 years of work with the Navy in reducing submarine noise, Westinghouse has amassed the know-how in depth required to design and build the quiet submarine equipment available today. New and improved production techniques have been developed to maintain the extraordinary tolerances that mean precision, super-quiet apparatus, while at advanced sound engineering laboratories, Westinghouse engineers continue to find new ways to make submarine equipment even more noise-free.

For example, experiments conducted in what is believed the first industrial testing chamber used to investigate motor noise have enabled Westinghouse to perfect new, ultra-quiet shipboard motors and motor-generator sets. The results of research on the causes of large power transformer noise at another special test location have been directly applicable to small, extra-quiet Westinghouse shipboard transformers. A thorough, continuing study of the sound produced by turbine-generators has prompted im-

PARTIAL LISTING OF WESTINGHOUSE QUIET EQUIPMENT developed for the nation's growing fleet of nuclear subs:
propulsion turbines and gears; vacuum equipment; emergency propulsion motors and controls, turboelectric propulsion systems; turbine-generator sets; motor-generator sets; switchgear, transformers; and auxiliary motors and controllers.



AT PHILADELPHIA, PA., shipboard turbines and generators undergo rigorous sound tests—but only on weekends so that external noise is at an absolute minimum. Test area is typical of sound research facilities in which Westinghouse has invested many thousands of dollars.

cut submarine equipment noise

portant design changes in turbine balance, tolerances and bearings. Other areas of Westinghouse noise research: semidirect propulsion systems, main gearing, thermoelectric and static devices.

Past Westinghouse research has sparked major advances in marine equipment—new gear designs, better turbine blading materials, and Thermalastic® insulation that greatly extends marine motor and generator life. Westinghouse noise research will bring about new, more efficient equipment for all ships.

Through experience and research, Westinghouse is uniquely qualified to supply the most reliable, maintenance-free ship propulsion and auxiliary apparatus tailored to your needs. One call to your Westinghouse representative triggers coordinated planning, manufacturing and delivery so that your equipment is perfectly matched, electrically and mechanically. Or write Westinghouse Electric Corporation, P.O. Box 868, Pittsburgh 30, Pennsylvania.

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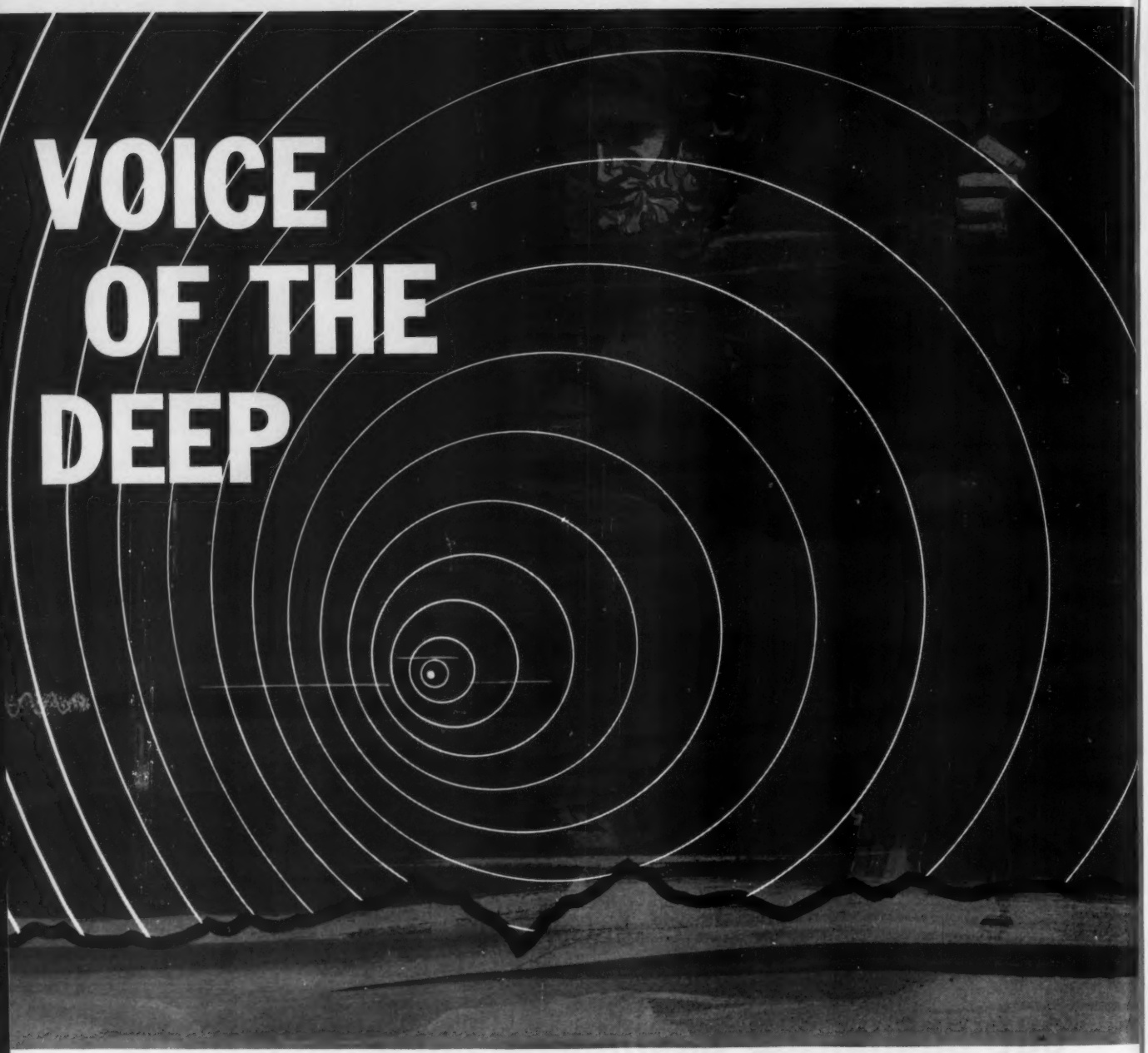

Neptune, the mythological ruler of the deep, had all the waters of the earth as his domain. Triton, his son, was assigned the vital task of communicating his father's commands to subordinates in all parts of the ocean.

The U. S. Navy has need of a counterpart for Triton. RCA is now assisting in this role through development of a communication link to our new nuclear powered Polaris-carrying submarines, anywhere on the seven seas.

RCA, in addition to its Polaris developments, is also working on many new Undersea Warfare systems such as detection, classification and destruction of enemy submarines as well as coordination of our friendly air, surface, and subsurface effort.

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DE LAVAL propulsion power U.S.S. DEWEY...

Built at the
Bath Iron Works, Bath, Maine,
the 512 foot, 5,600 ton
U.S.S. DEWEY
was commissioned on
December 12 at the
Boston Naval Shipyard

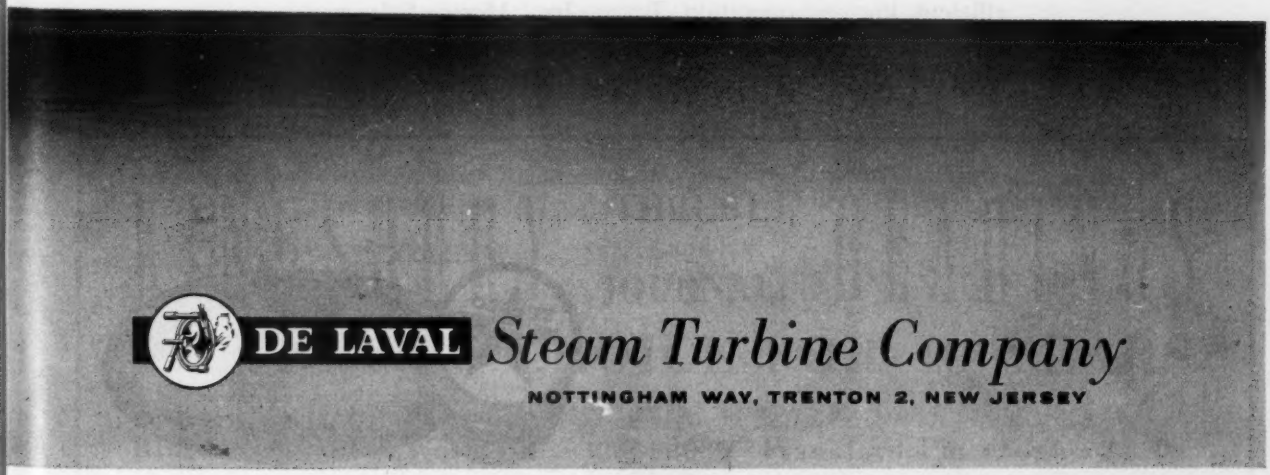
units

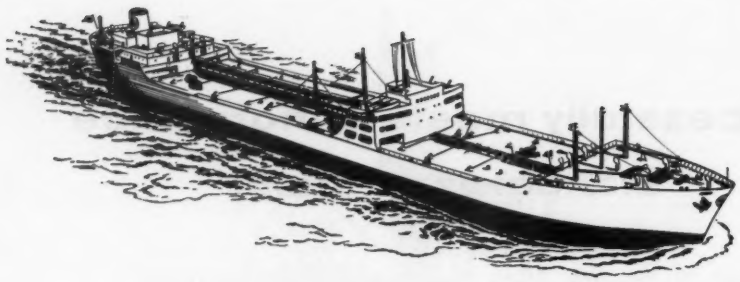
first of the new DLG class

Successfully meets performance standards in trials

First of the new class of guided-missile destroyer-leaders, the U.S.S. DEWEY is powered by two De Laval cross compound main propulsion turbine units and reduction gears. In addition, De Laval manufactured and supplied four turbine-driven fuel oil service pumps, two turbine-drive lube oil pumps, port fuel oil pumps, diesel oil transfer and fuel oil transfer pumps.

De Laval will also provide the main propulsion and auxiliary units for four additional DLG class vessels, and is proud to have once again contributed to a distinguished naval event.





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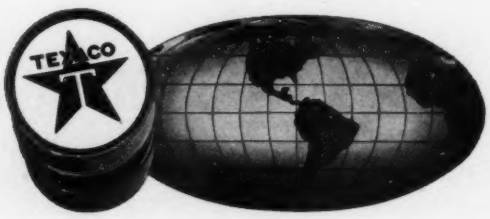
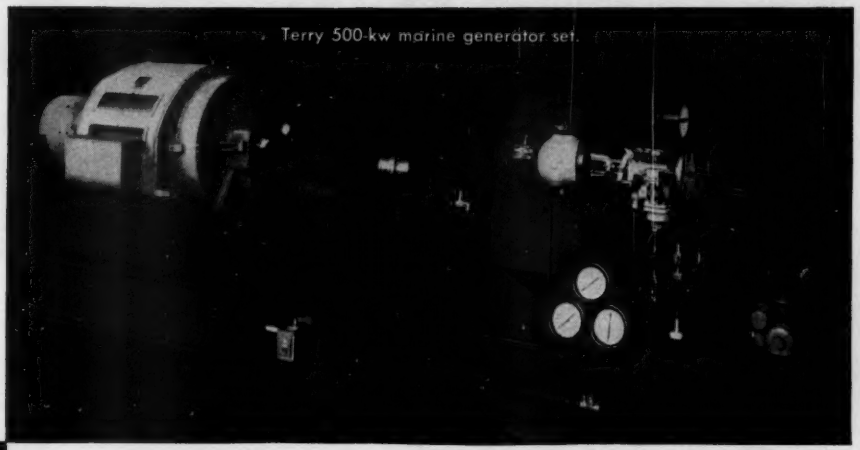
Newly expanded bunkering service, on a world-wide basis, now enables Texaco to serve your vessels even better.

There is a complete line of Texaco Marine Products—lubricants, fuels and protective coatings for all types of vessels. These, combined with famous Texaco engineering and delivery service, are potent factors in assuring dependable, efficient, low cost operation. Texaco Inc., *Marine Sales and Bunkering Services Division,* 135 East 42nd Street, New York 17, New York.



QUALITY AND SERVICE AROUND THE WORLD

Terry steam turbines


Terry 500-kw marine generator set.

Terry solid-wheel turbine with upper half of casing removed.

Dependable, compact, efficient . . . Terry marine turbines are specially designed for driving generators, boiler-feed pumps, fuel-oil pumps, compressors, etc., aboard ship. They are the result of over fifty years of experience in designing equipment for commercial and naval vessels.

Turbines ranging from 5 to 3000 hp are built in the Terry solid-wheel design as well as in axial-flow, single-stage and multi-stage types.

Complete details of turbines for any application will be gladly furnished.

THE TERRY STEAM TURBINE CO.
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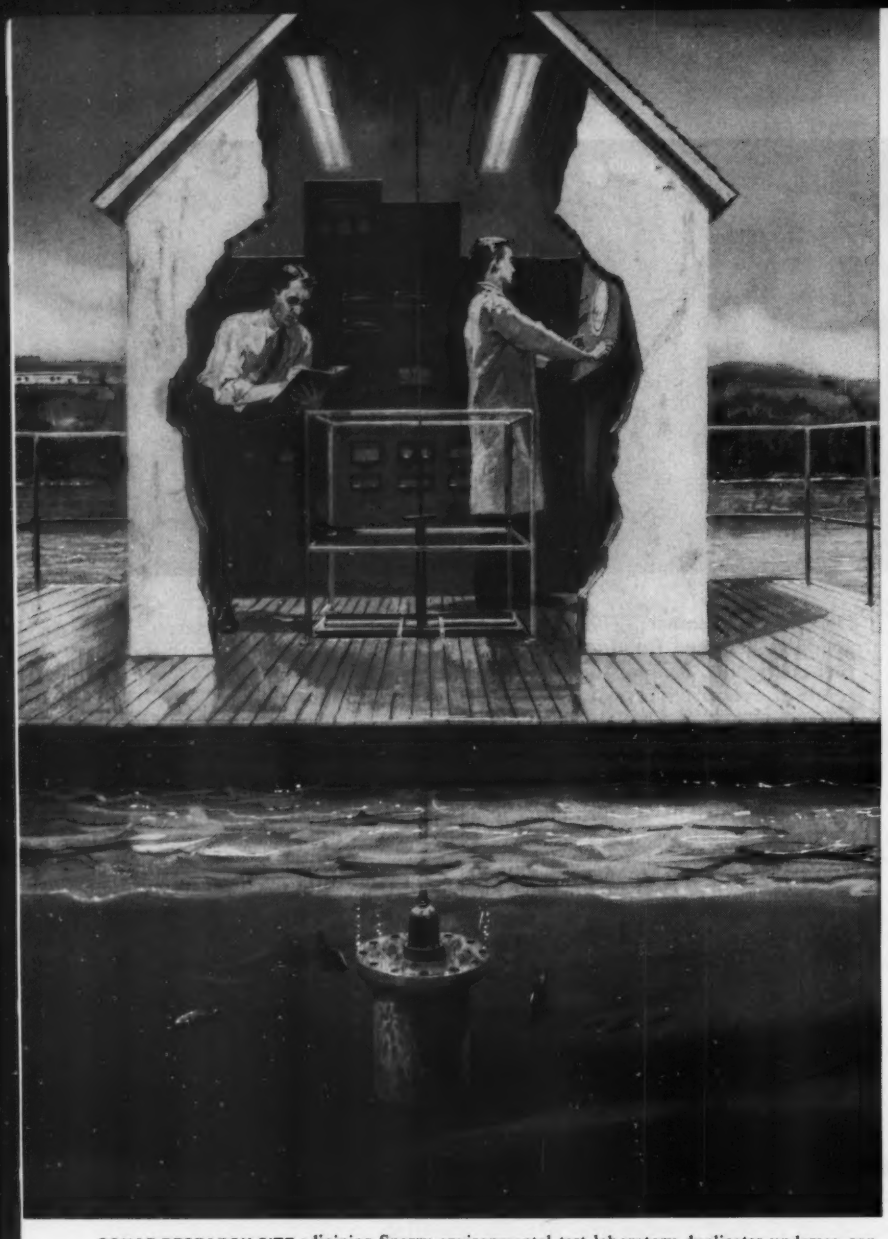
KINGSBURY THRUST and JOURNAL BEARINGS

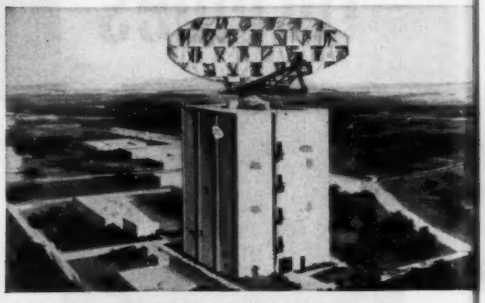
THE NAVY'S CHOICE FOR 40 YEARS

Kingsbury Machine Works, Inc. KINGSBURY **Frankford, Philadelphia 24, Pa.**



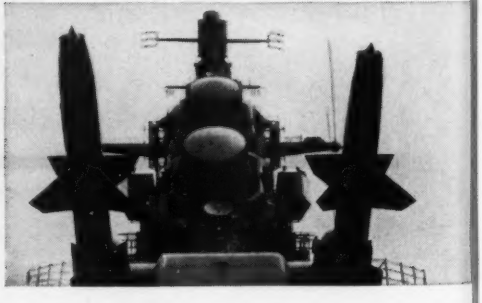
SONAR RESEARCH SITE adjoining Sperry environmental test laboratory duplicates undersea conditions on small scale, simulates targets and myriad problems of anti-submarine warfare. Sonar search device is lowered into "depths" while engineers conduct tests in floating lab above.

PORTABLE FIELD RADAR provides Army with combat surveillance of enemy movements. Headphone signal reveals presence of moving vehicles or personnel in battle area.



TOWER OF STRENGTH in U.S. defenses is strategic network of huge radars for warning of incoming missiles and aircraft. Developed by Sperry in cooperation with the Air Force, system has 70-ton antenna, 85-foot tower.

SHIPBOARD MISSILE GUIDANCE RADARS direct Navy's Talos to target. Other Sperry systems search, track, select right missile for target, aim, fire and guide missile to target—then evaluate "kills"—all automatically.



Detecting the Unseen to Protect U. S. Defenses

Scientists develop new and sophisticated means of listening and searching, to combat the threat of new weapons

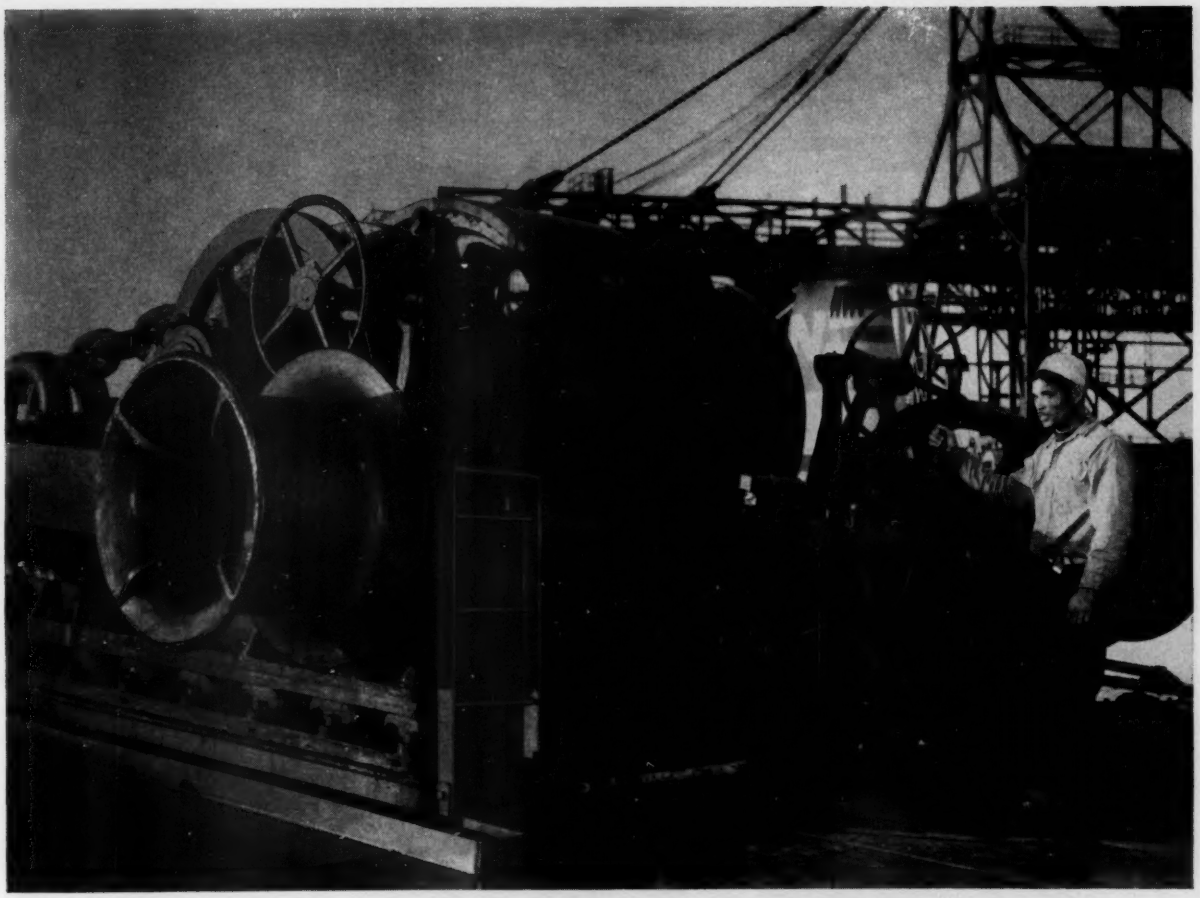
ONE OF A SERIES:

THE STORY BEHIND THE STORY
of Sperry's Surface Armament Division

The new nuclear and missile-firing submarines are swift, silent, invisible. They can cruise in the ocean depths for weeks and months, or voyage from the Pacific to the Atlantic under the polar ice cap. The difficulty of detecting them is an advantage when they're ours, and an ever-present threat to our security when they're hostile.

Such problems of detecting and guiding offensive and defensive weapons are being tackled and solved by engineers at Sperry's Surface Armament Division, working in cooperation with all the military services. Advanced techniques in sonar sound detection and torpedo fire control are being applied to anti-submarine defense projects. In addition, sophisticated and advanced radar systems for tactical search, target tracking, missile guidance, area defense and other developments help make effective such weapons as Polaris, Talos, Terrier and Nike Zeus. Sperry also provides supporting systems so important to reliability—and to keeping our defenses in readiness. Surface Armament Division, Sperry Gyroscope Company, Division of Sperry Rand Corporation, Great Neck, N. Y.

SPERRY



"K" Monel shafts in deck machinery can handle the toughest jobs

Shafting in auxiliary machinery aboard ship must be strong and tough, and corrosion-resisting, to keep vital equipment operating without interruption for long periods, both at sea and in port.

"K" Monel* age-hardenable nickel-copper alloy is one shafting material with *all* of these properties!

It possesses the excellent corrosion resistance of Seagoin'* Monel alloy together with the added advantages of greater strength and hardness, because "K" Monel is age-hardenable (capable of having its properties increased by heat treatment).

More specifically, here's what "K" Monel offers:
High Strength, stiffness, and torsional properties to transmit power with minimum vibration. "K" Monel has remarkable resistance to fatigue — to the repeated stresses a shaft has to undergo.
Hardness to resist abrasion and scoring. This means more protection against shaft wear — longer bearing life.
Corrosion resistance. This nickel-copper alloy resists corrosion, pitting, and corrosion fatigue in sea water as well as fresh and polluted waters.
Galvanic neutrality, when coupled with bronze pump bodies and bearings.
Non-magnetic. "K" Monel alloy is non-magnetic under ordinary conditions, and remains so down to −150°F.

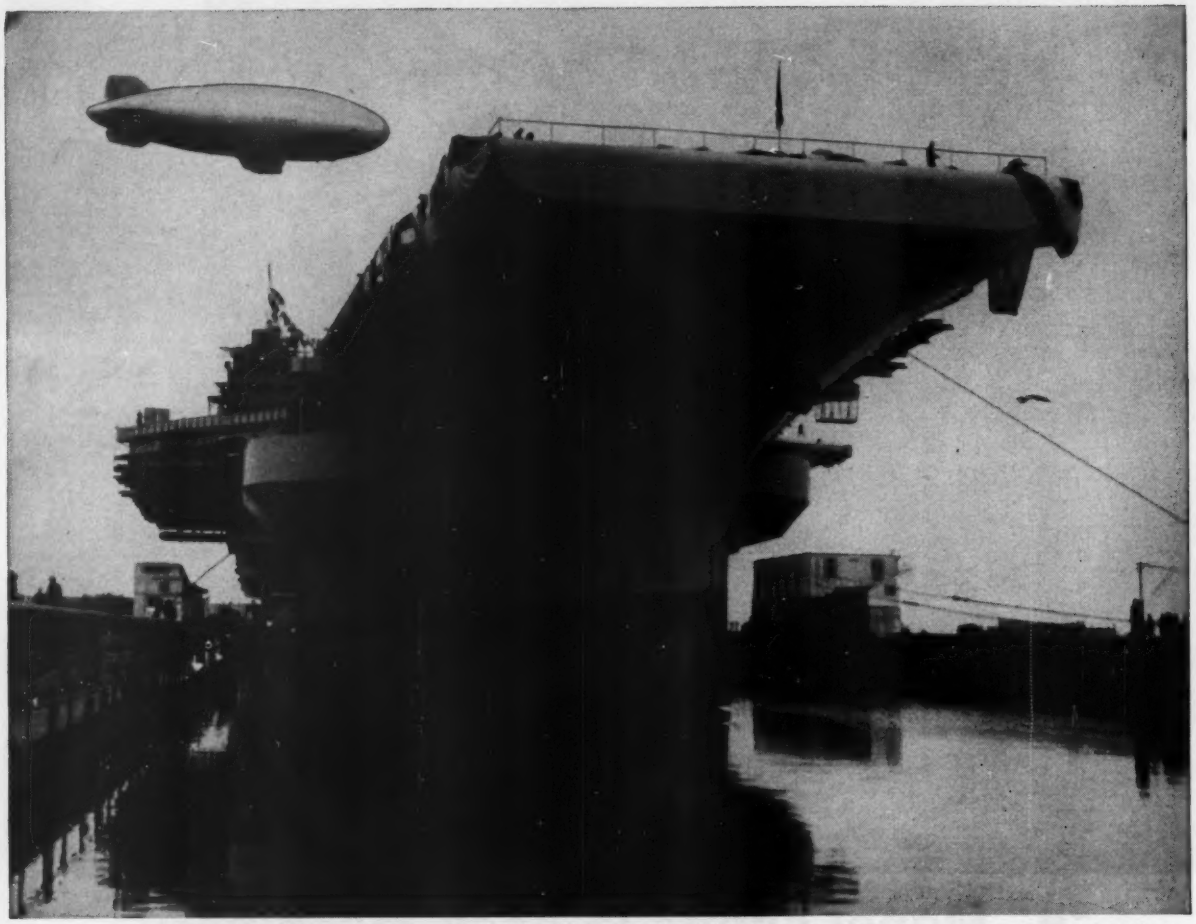
Time and time again, this seaworthy alloy has proved itself, below decks and topside...in deck machinery, sleeves, valves, wearing rings, springs, and in pumps of all kinds. These are only a few uses for this versatile alloy.

If you would like to know more about "K" Monel alloy, write for our 28-page reference manual "Engineering Properties of "K" Monel and "KR" Monel". We'll also be glad to answer your questions about other high nickel alloys. Just write to:

*Inco trademark

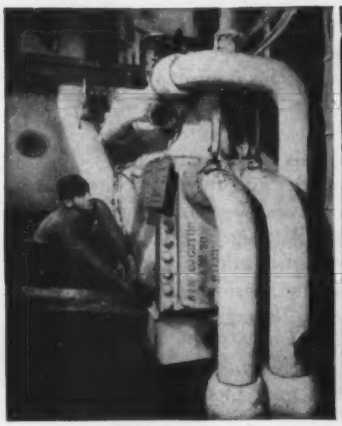
HUNTINGTON ALLOY PRODUCTS DIVISION
The International Nickel Company, Inc.
67 Wall Street New York 5, N. Y.

"K" MONEL

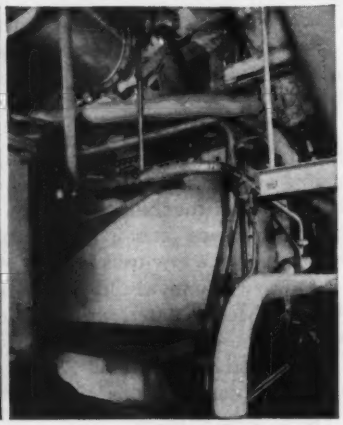


The U.S.S. Forrestal (above) and the U.S.S. Saratoga are both fitted with equipment engineered and built by C. H. Wheeler. The U.S.S. Ranger, the U.S.S. Independence and the U.S.S. Kitty Hawk, now under construction, will also be Wheeler-equipped.

SUPERCARRIERS NEED "SUPER" EQUIPMENT



Vacuum Drain Tank Ejector, built by Wheeler, which has been installed in the U.S.S. Saratoga, sister ship of the U.S.S. Forrestal (above).



Main Condenser (forward) on U.S.S. Saratoga. Nearly all U.S. Navy ships—even atomic submarines and supercarriers—have Wheeler equipment aboard.

The nation's two new "super-equipped" supercarriers now afloat, the U.S.S. Forrestal and U.S.S. Saratoga, contain marine machinery custom-engineered and precision-built by C. H. Wheeler. The three supercarriers which are now under construction, the Independence, the Ranger and the Kitty Hawk, will also use Wheeler equipment.

On the Saratoga are two Wheeler Marine Condensers, which in combination with newly-designed turbines, develop 200,000 horsepower to drive this beautiful 60,000-ton supercarrier in excess of 30 knots. Wheeler Anchor Windlasses, Ordnance Elevators, Capstans, Winches, Auxiliary Gland Exhaust Condensers and Distilling Plant and Vacuum Drain Ejectors are also installed on the 1,040-foot Saratoga.

Marine Division

C·H·Wheeler Mfg·Co·

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Philadelphia 32, Pennsylvania

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Result, more men work more continuously on cleaning, painting, inspection and repair. Big overhead cranes, that once did this work-positioning job far less efficiently, are freed to handle heavy duty repairs. Up goes overall overhaul speed. And your ship is often ready to go back into profitable service days sooner.

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an area
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Quiet, swift and deep-running, nuclear-powered submarines demand new performance from undersea warfare devices.

Equipment is urgently needed for improved underwater detection, classification and localization.

Stromberg-Carlson research programs will result in new undersea warfare electronic systems.

Unequalled tank-test facilities and automatic test instrumentation enable Stromberg-Carlson to conduct the exhaustive tests required to develop the complex ASW equipment of the future.

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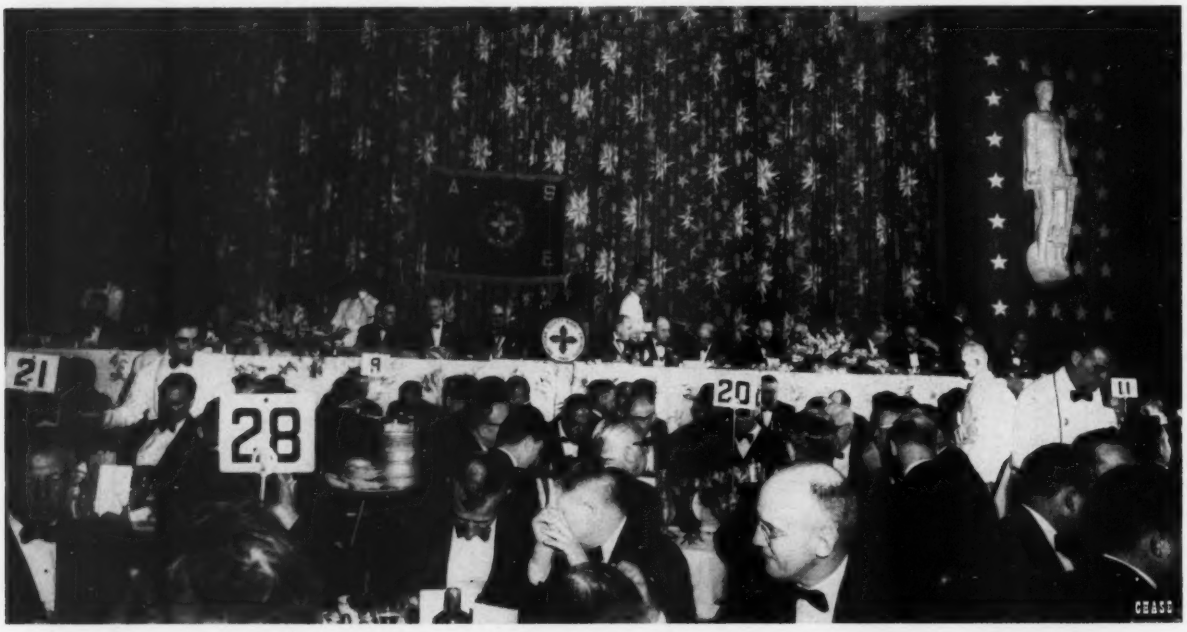

THE SPEAKERS TABLE, Admiral Dolan, Past-President; Admiral Cowart, Past-President; Mr. Herr, Honorary Member; Admiral Williams, Past-President; Admiral James, Chief, Bureau of Ships; Dr. Lyon, Awardee; Admiral Burke, Chief of Naval Operations; Mr. Jones, Principal Speaker; Admiral Cronin, President; Admiral Wilson, Deputy Chief, Naval Operations; Admiral Mills, Past-President; Mr. Blunck, Statler General Manager; Mr .Fessenden, Past-Administrative Assistant; Admiral Furth, Past-President; Admiral Bennett, Chief, Naval Research; Admiral Thiele, Engineer-in-Chief, USCG; Captain Landers, Secretary, Society of Naval Architects & Marine Engineers.

Honored Guests Gathered Together Before the Banquet

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Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 72 MAY, 1960 NUMBER 2

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NAVAL ENGINEERING

Definition: NAVAL ENGINEERING is the art and science applied in the design, construction, operation and maintenance of naval ships and their installed equipment.

SECRETARY'S NOTES

The Annual Banquet

The Society's annual party is the principal news item to be reported on in this issue. For reasons which are somewhat obscure, this the 42nd banquet was smaller by about ten percent than those of recent years have been. Aside from that, and this detracted from the affair only in that fewer persons had the privilege of participating, the enjoyment, camaraderie, and pleasure which we have come to expect were undiminished.

The contribution of the staff of the Statler Hilton Hotel seems to improve on perfection each year. They continue to do a superb job of catering and of furnishing all of the necessary arrangements for the banquet itself and for the many pre and post banquet receptions where the soul of the meeting is developed.

The President of the Society, Rear Admiral R. E. Cronin, USN officiated as host at a reception preceding the banquet and presided over the banquet

General view of the Banquet facing the Speakers Table

The Speaker in Action. Admiral Burke, Admiral Cronin, Admiral Wilson and Admiral Mills appear

and the short meeting which followed. The program of this meeting was simple, marked with a note of informality which we have tried to develop. Between the Invocation which was delivered by Navy Chaplain Francis T. O'Leary, Ch.C., U.S. Navy, and the National Anthem rendered by a contingent of the Navy Band which had furnished enjoyable dinner music throughout, there were three main events.

First the President announced that the following members had completed half a century of membership and would receive paid up Life Membership certificates:

C. H. Johnson
RADM Clark H. Woodward, USN (Ret)
T. H. Yeager
J. F. Metten

This announcement was followed by the presentation of the ASNE Award for 1959. This award was made for the second time this year and it is significant that both winners have made their outstanding naval engineering contribution in the field of electronics and both are employees of the Naval Electronics Laboratory of San Diego, California.

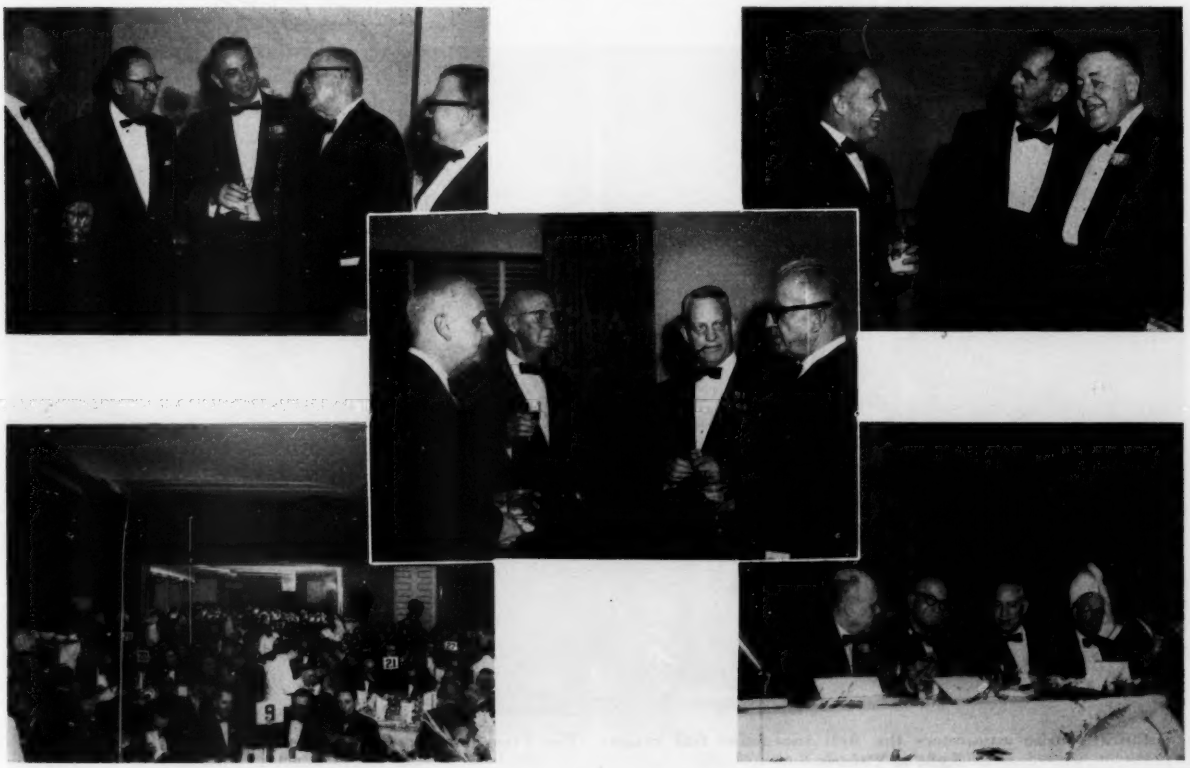
The ASNE Award was made to Dr. Waldo K. Lyon for his great contributions to polar navigation of submarines. Dr. Lyon was nominated for the award by Rear Admiral L. R. Daspit, USN, Commander, Submarines, Atlantic Fleet. The full citation by Admiral Daspit is published on page 202 with a biography of Dr. Lyon. Rear Admiral W. A. Dolan, USN, past-President of the Society and chairman of the Committee which selected the awardee from all nominations received, presented the Society's gold medal and an engrossed citation to Dr. Lyon. The President, Rear Admiral Cronin, presented a certificate of Life Membership.

The climax of the evening was the principal address by the Honorable Roger W. Jones, Chairman of the U. S. Civil Service Commission. His title, "The Administrator and the Professional Man" does not fully describe his message which was most appropriate to this Society gathering. A biography of Mr. Jones and the text of his address are published beginning on page 205.

Submarine Motif

Sixty years ago, on 11 April 1900, the U. S. Navy purchased its first submarine, the U.S.S. *HOLLAND* from the Electric Boat Co. On 9 April 1960 the Navy commissioned its second fleet ballistic missile submarine, the POLARIS firing USS *PATRICK HENRY* at Groton, Connecticut where it was built by the Electric Boat Division of General Dynamics Corp.

A point by point comparison between *HOLLAND* and *PATRICK HENRY*: size, speed, armament, motive power, communications, navigational equipment, habitability, endurance and so on, will pro-



The American Society of Naval Engineers, Inc.

The members of the American Society of Naval Engineers extend their sincere and cordial greetings to the

Royal Institution of Naval Architects

on the attainment of its

One Hundredth Anniversary

We, in our youth of 72 years, view with great respect the accomplishment of the Royal Institution and its outstanding and noteworthy contributions to the art and science of Naval Architecture.

As we look toward the date when you will celebrate your duo-centennial it is with the hope and expectation that the professional admiration which the Institution has merited in its first hundred years will be enhanced in a geometrical progression.

With our best wishes for the success of your Centenary meeting in London in May 1960.

Secretary Treasurer

President

Washington, D.C.
May 1960

Admiral Burke announces the first successful full range flight of *Polaris*.

The President, Admiral Cronin, and Dr. Lyon, Winner of the ASNE Annual Award.

vide a partial gauge of the advances in Naval Engineering which a brief 60 years has seen.

This issue of the JOURNAL does not print up this really phenomenal progress but it has, largely through chance, acquired a strong submarine motif which can be interpreted as this Society's salute to the Navy for its magnificent submarine achievements.

As a start for any informed Naval Engineer to ponder on what his profession has accomplished, this table is presented:

	Holland	Patrick Henry
Length	54 feet	380 Feet
Armament	1-14 inch torpedo	Torpedos and Polaris missiles
Crew	7	2-100 each
Endurance	10 hours	Months
Electronics	None	Considerable
Propulsion	Gasoline Engine	Nuclear power

ASNE Award

As elsewhere noted, the Society has made its second annual award for an outstanding naval engineering achievement. In full justice to the two persons who have won this award and to all those who will win it in the future, it is important that its significance be recognized. With all of the facilities which it possesses the Society canvasses the **world** for nominations of U. S. citizens who have made outstanding contributions to the profession during the year. Candidates are not limited to Naval Engineers nor to members of the Society. **Any U. S. citizen** regardless of age, profession, or residence is eligible. From all nominations which are received, selection of the awardee is made by a committee composed of three past-Presidents of the Society.

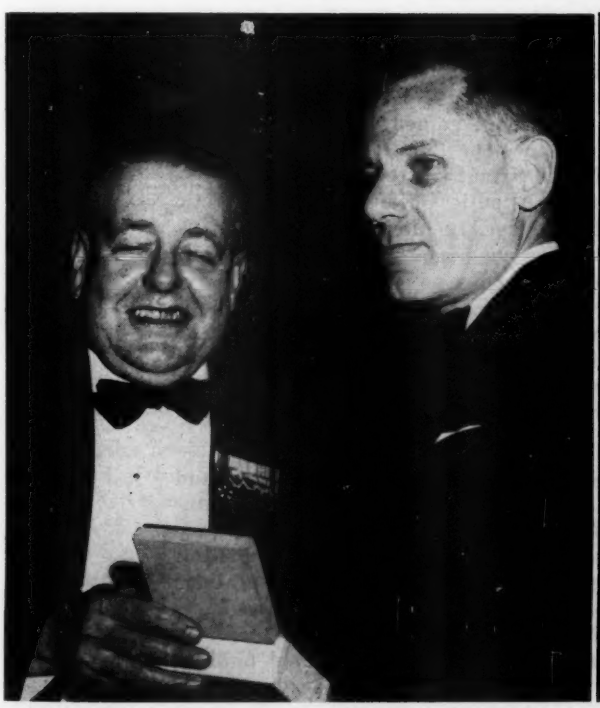
The ASNE Award is of great significance and anyone who holds it may well be considered worthy of acclaim. Members of the Society can contribute to the enhanced value of the award with time by continuing to honor it by being ever on the alert to note and report likely candidates.

Royal Institution of Naval Architects

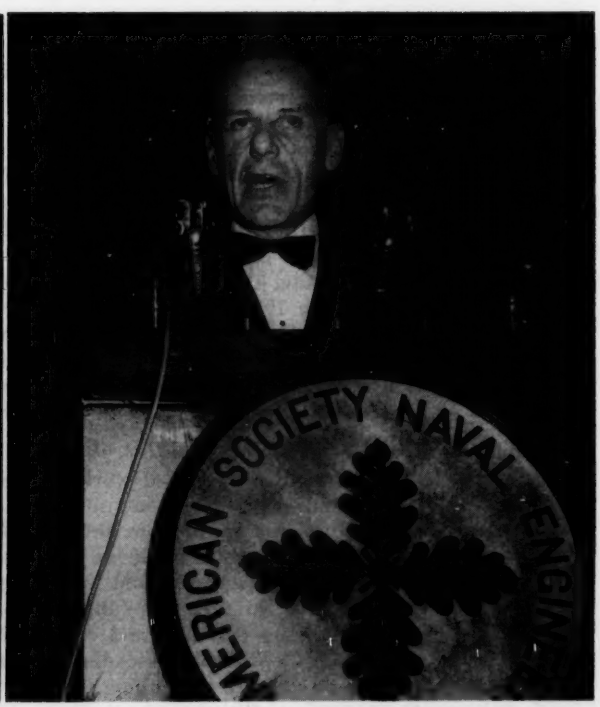
The Royal Institution of Naval Architects, is celebrating its one-hundredth birthday in London, England this month. Mr. Ralph A. Miller, a member of this Society and of the Royal Institution is attending the Centenary meeting and will represent the Society on this occasion. He carries and will present the engrossed greetings of the Society. A replica of this greeting will be found in these pages.

By-Law Changes

The Council has under consideration, a change in the By-Laws which will substitute a Junior Membership and a Student Membership for the present Junior Membership. If this is adopted by the Council, a specific By-Law change will be submitted to the membership for its consideration, with the ballot in October 1960.



Admiral Dolan Presents the ASNE Medal to Dr. Lyon



Dr. Waldo K. Lyon Acknowledging Award

The American Society of Naval Engineers

takes pleasure in Commending

WALDO K. LYON, Ph.D.

For exceptionally meritorious achievement in connection with the U.S. Navy effort to explore and develop the capability for sustained submarine operations in the Arctic Ocean:

"For exceptionally meritorious achievement in the performance of outstanding services while serving at the U.S. Naval Electronics Laboratory, San Diego, California and on board the nuclear submarine USS *SKATE* (SS(N) 578) during the Arctic Cruise of 1959.

In 1946 Dr. LYON developed the first crude sonar equipment for under-ice operations, which furnished vital support to the Navy's first Arctic exploratory cruise by submarine in the Bering Sea and Chuckchi Sea. His personal participation in this cruise provided the essential technical knowledge and Arctic experience necessary to accomplish the cruise. Since this first cruise Dr. LYON has dedicated his life's work to giving our Navy control of the Arctic Ocean. In the period 1946-1953 he participated in several diesel submarine operations in the Bering Sea and Chuckchi Sea during which he continually improved the electronic equipments and submarine operational capabilities for under-ice operations. He did much to keep alive the idea of submarine Arctic operations by his own enthusiasm, confidence, and dedication to duty. The advent of the nuclear powered submarine, with its unlimited submerged endurance, overcame the major remaining obstacles to under ice operations. Dr. LYON was instrumental in the planning of nuclear submarine Arctic cruises and in 1957 he participated in the Arctic voyage of USS *NAUTILUS* (SS(N)571), operating and evaluating greatly improved electronic ice detection equipment which was designed, developed and constructed under his direct supervision. With the knowledge gained during that cruise, he developed additional equipments to enhance the Arctic capabilities of nuclear submarines. This permitted *NAUTILUS* in 1958 to complete the first transpolar crossing from the Pacific to the Atlantic Ocean under the Arctic ice pack. Dr. LYON participated in that voyage. In March 1959 Dr. LYON was on board USS *SKATE* (SS(N)578) when she surfaced at the North Pole, demonstrating the nuclear submarine's tremendous potential for arctic service. Late in 1959 he assisted in outfitting USS *SARGO* (SS(N)583) for her historic 31 day winter Arctic cruise north of Alaska, personally participating in that trip in early 1960. The *SKATE* cruise of 1959 and this most recent cruise of *SARGO* of over 6000 miles under the ice, marked the culmination of Dr. LYON's long sought goal—submarine Arctic operations on a year-round basis.

Throughout his years of work on the development of Arctic equipment and in personal participation in submarine Arctic operations, Dr. LYON gave unsparingly of his enthusiasm, technical knowledge, and time. He not only provided the technical knowledge for developing the necessary equipments, but he provided the professional knowledge and experience of Arctic operations to keep alive the idea and support submarine operations under the ice. He is an outstanding engineer and citizen. His devotion to duty is an example to all, and his enthusiasm, leadership, and extraordinary professional abilities have been and are continuing to be of tremendous value in the service of our Navy and our Country.

ASNE AWARD WINNER

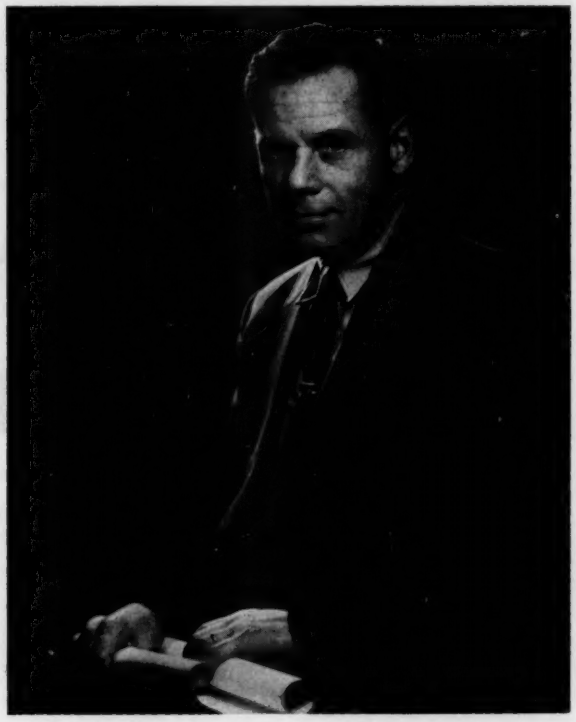
Dr. Waldo K. Lyon

Dr. Waldo K. Lyon is a supervisory physicist and holds the position of Head of the Submarine and Arctic Research Branch of the U. S. Navy Electronics Laboratory. He has been associated with the Laboratory in a supervisory capacity since its inception in 1945 and began his work with the Federal Government as a member of the Laboratory's prodecessor organization—the U. S. Navy Radio and Sound Laboratory—in 1941.

Dr. Lyon's most recent notable accomplishments were his participation in the 1959-60 winter expedition to arctic waters in the U.S.S. *SARGO-STATEN ISLAND* expedition and the U.S.S. *NAUTILUS'* now famous dash under the Arctic Ocean ice pack and across the North Pole in August of 1958. He was the Senior Scientist for both voyages. Dr. Lyon also was Senior Scientist aboard the *NAUTILUS* during the Polar Arctic Expedition of 1957 as well as for the first winter under-ice expedition to the North Pole by the U.S.S. *SKATE* in 1959. These cruises have collected scientific data for more than 12,600 miles under arctic sea ice.

All told, Dr. Lyon has been Advisor and Chief Scientist for 20 Navy expeditions to the arctic and antarctic areas. He was also Senior Scientist of the Wave Measurement Group of Operation CROSSROADS—the A-bomb tests at Bikini Atoll—in 1946.

Dr. Lyons' contributions to physics made not only during the many sea expeditions but in the laboratory where he has developed unique methods for researching, have been officially recognized as outstanding. He received in 1946 a commendation for his work in Operation CROSSROADS from the Joint Task Force Commander. In 1955 Charles S. Thomas, Secretary of the Navy, presented him the Navy Distinguished Civilian Service Award, the highest honorary award the Secretary of the Navy can bestow, "in recognition of his invaluable contributions to the national security and to the Navy through the advancement of science." The Department of Defense highest civilian award, the Distinguished Civilian Service Award, was given Dr. Lyon in 1956 by the Secretary of Defense Charles E. Wilson for ". . . the courage and ability he has demonstrated in numerous research expeditions to the Arctic. Dr. Lyon's (contributions to the solutions of) the problems of navigation and of the techniques necessary for Naval operations in the Arctic have made him one of the Nation's leading authorities on that area and one of the most valuable civilian employees of the Department of Defense." In addition Dr. Lyon has been officially commended for his part in making successful the two polar expeditions of the U.S.S. *NAUTILUS* in 1957 and 1958.

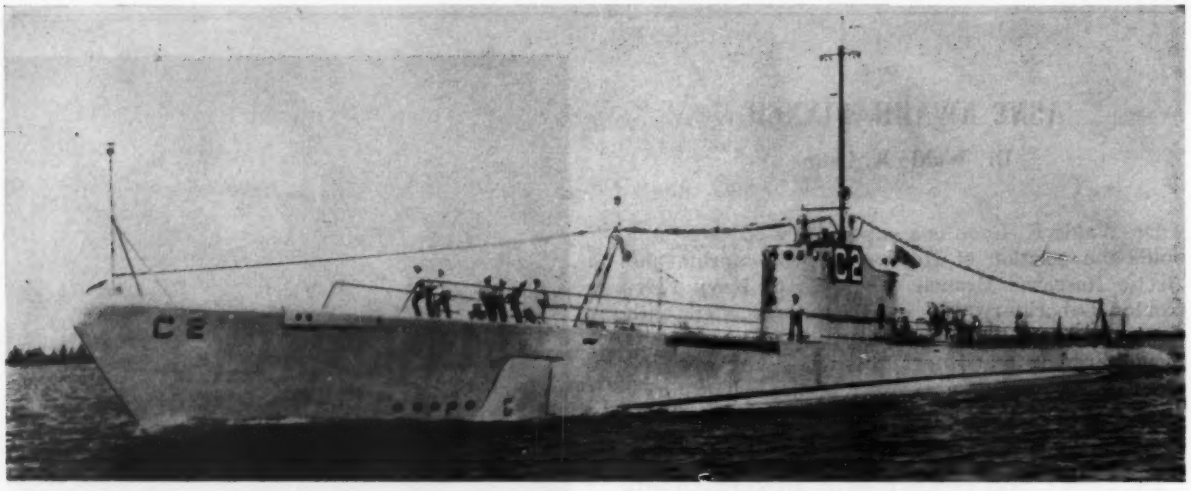


DR. WALDO K. LYON

Dr. and Mrs. Lyon and their two children, Lorraine and Russell, live on Point Loma in San Diego. Lorraine attends the University of California at Riverside and Russell is a junior at Pt. Loma Senior High School. Both parents are active in church and civic affairs, and the family relaxes by playing in tournaments of the American Badminton Association.

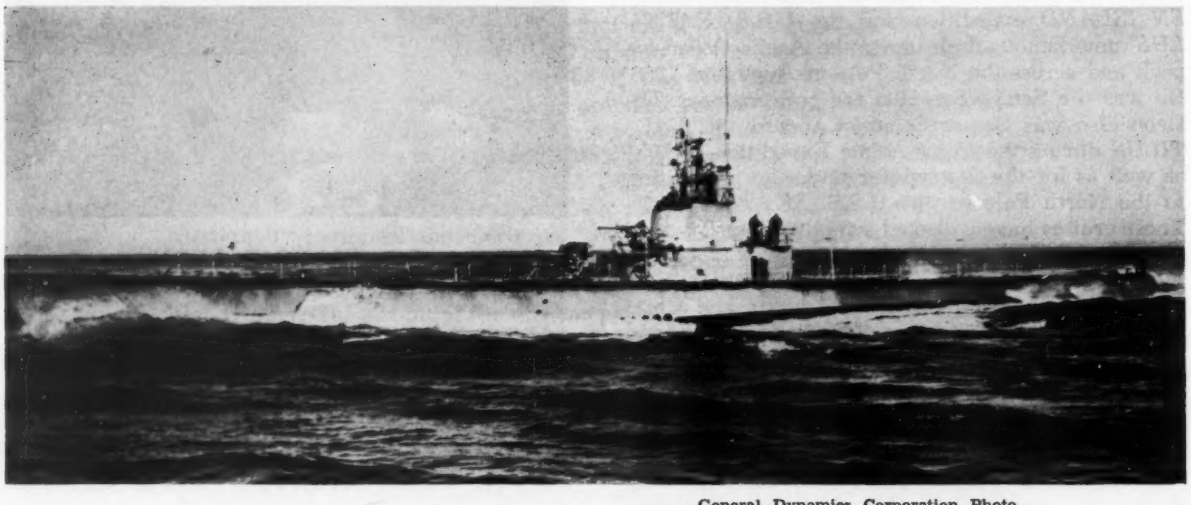
Dr. Lyon is a Member or Fellow of half a dozen national and international scientific societies: American Geophysical Union, American Physical Society, Acoustical Society of America, Arctic Institute of North America, British Glaciological Society and Scott Polar Institute, and American Association for the Advancement of Science.

Dr. Lyon was born in Los Angeles, California, in 1914. He received his AB degree in physics from the University of California, Los Angeles, in 1936; his MA in 1937; and his PhD in 1941. After earning his MA degree he became an Assistant Instructor in Physics at UCLA, remaining there until 1941 when he joined the U. S. Navy Radio and Sound Laboratory.



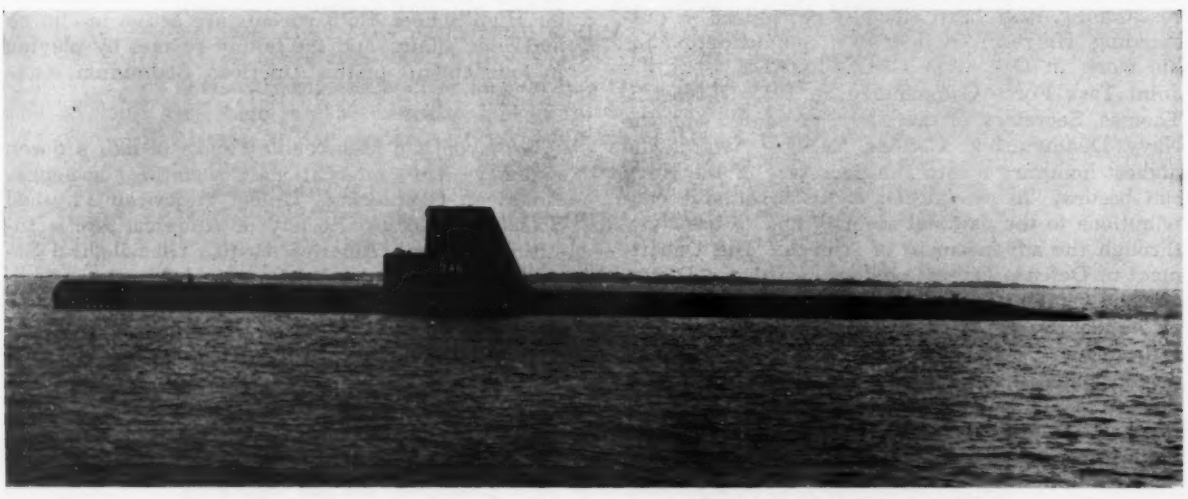
General Dynamics Corporation Photo

SS13 *Stingray* (C-2) C Class like *Holland* but larger. Launched 1937.



General Dynamics Corporation Photo

U.S.S. *Cobea* (SS245) Fleet Type. Launched 1943.

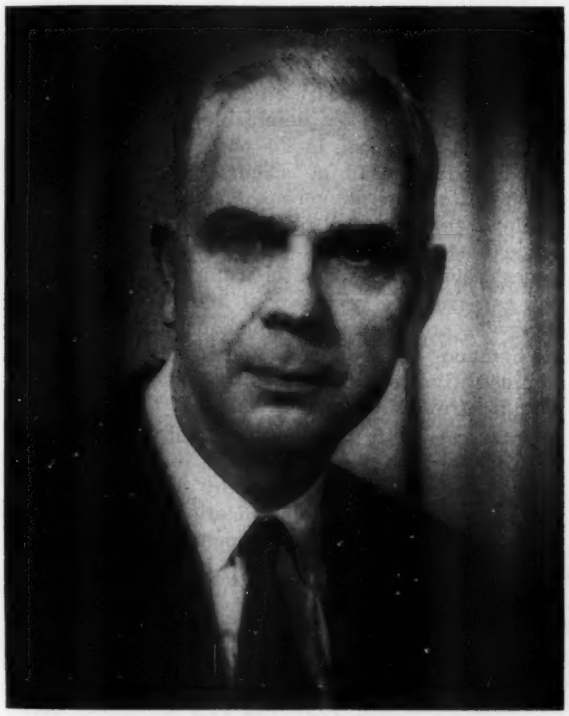


General Dynamics Corporation Photo

U.S.S. *Corporal* (SS 346) Guppy Type. Launched 1945.

THE ADMINISTRATOR AND THE PROFESSIONAL MAN

THE PRINCIPAL SPEAKER
ROGER W. JONES
CHAIRMAN
U.S. CIVIL SERVICE COMMISSION



ROGER W. JONES

Roger W. Jones took office as Chairman of the United States Civil Service Commission on March 9, 1959. The President nominated him on January 17, 1959, to fill the vacancy created by the resignation of Harris Ellsworth, effective February 28, 1959.

Mr. Jones, a long-time career civil servant, joined the Bureau of the Budget in 1939, and served with it until his appointment to the 6-year term as CSC Chairman. He moved into his new position from the post of Deputy Director of the Bureau of Budget, to which he had been appointed on September 11, 1958.

Prior to that, he had served for 6 months as one of the Bureau's three statutory assistant directors. He served as Assistant Director for Legislative Reference, Bureau of the Budget, under two Presidents, from February 1949 to March 1958.

He entered the Federal service in 1933 and served in various posts with the Central Statistical Board before joining the Budget Bureau's staff in 1939. When the United States entered World War II, he was the Bureau's Administrative Officer.

In 1958 he was one of the first five recipients of the "President's Award for Distinguished Federal Civilian Service," and he was also one of the first ten persons to receive the National Civil Service League's "Career Service Award" in 1955.

He was ordered to active duty as a captain in the Officers Reserve Corps in March 1942 and assigned to duty with the Combined Chiefs of Staff, Munitions Assignment Board. He was promoted to major in May of that year, to lieutenant colonel in March 1943, and to colonel in May 1945. He was released to inactive duty in December 1945. He was awarded the Legion of Merit and the Order of the British Empire.

Born in New Hartford, Conn., on February 3, 1908, Mr. Jones received a bachelor's degree from Cornell University in 1928 and a master's degree from Columbia University in 1931. He is a member of the Cornell Club of Washington, D. C. and of Sigma Phi Epsilon and Delta Theta Phi.

Address by
ROGER W. JONES
Chairman, U. S. Civil Service Commission,
To the American Society of Naval Engineers,
At the Statler-Hilton Hotel, Washington, D. C.
On Friday Evening, April 29, 1960

MR. CHAIRMAN, members, and guests of The American Society of Naval Engineers:

When your organization was founded in 1888, it adopted as its central purpose the promotion of knowledge in the fields of marine engineering and naval architecture. Both pursuits are among the most ancient and honorable of professions. In fact, as you no doubt have been advised many times in the past, you are descended professionally from Methuselah himself. That worthy was only 369 years old when his grandson, Noah, was born. In the remaining 600 years of the old man's life he had just about time enough to impart to his grandson the knowledge and skill necessary to turn the Lord's oral specifications into a seaworthy ship. With such authority of the Bible firmly behind them, it is easy to see why the first builders of the Clipper ships set hopeful store in their belief that a long life might produce one good ship.

Tonight I hope not to take you as far afield from the purposes of your Society as the title of my remarks might indicate. Whatever excursions I may make in other directions are deliberately undertaken. With your status as professional men securely ordained by Holy Writ, I am sure you have no fear of after-dinner evangelism from an upstart administrator.

The complexity of your profession and the difficulty of mastering it have given the engineers and architects of the marine world a notable, hardheaded realism. Time and again this realism has kept them in the forefront of those who, throughout history, have dared to let new ideas triumph. Ever since Noah "found favor in the eyes of the Lord" your kind have been ready to challenge accepted ways of doing things according to the standards of their day. At times your success was most aggravating to those who liked things as they were. Three examples from our own maritime history will prove my point: invention of the steamboat, development of ironclad warships, and acceptance of the belief that airplanes could be flown off, and landed on, the unstable runway of a ship's deck.

It seems to me fitting, in the light of this tradition in your profession, to ask you once again to venture into daring. I want you to share with me the advocacy of a proposition that is not making headway fast enough to suit me. In simplest terms, it is advocacy of a much closer working relationship between the administrator and the professional men. There are two facets to this proposition. The first is that we should use more trained administrators without regard to their possession of professional accomplishments in fields other than administration. The second is that we should try harder to convince professional men, especially scientists, of the benefits to be derived from acquiring and using skill in administrative techniques. I feel obliged to advocate this proposition both because I believe it is sound, and because the experience of the Civil Service Commission has demonstrated that it is necessary.

In today's complex world of blending science, technology, administration, and national ideals into a system of international progress understanding, and good will, we have neither enough professional men nor enough administrators to go around. In fact, we are so short of both professional and administrative talent at senior levels that the Federal Government may soon be hard put to it to keep some of our national programs moving as rapidly and as competently as they should move.

It behooves us, then, to mix and to use both professional and administrative talent to the best advantage, making the most of the synergism which results. Best advantage certainly is not to be found in fostering the traditional lack of sympathy for each other's point of view which, for decades, has characterized relationships between the professional man, usually scientifically trained, and the administrator, usually trained in the integrative techniques of unscientific (but practical) empiricism. However understandable, and even defensible, this lack of sympathy may have been in the past, we can no longer afford it. It is draining strength from both sides, and resulting in dangerous waste and stalemate. I believe that the skill of the administrator can enhance professionalism, and that, in many circumstances, even modest use of training in administration can free the professional man from what will otherwise be inexorable, time-consuming, and stifling demands on his energy and originality. Modern adminstrative requirements do not overwhelm those who are trained to meet them.

Until recently it has been heretical to believe that the gap between the professional man and the administrator could be bridged by such unscientific procedures as better communication and imposition of a required mutual interdependence. Unwillingness to adopt a simple solution has resulted in too much attention by administrators to an effort to make administration into a science and to surround it with all of the paraphernalia of the scientific method. Scientific apparatus and method are useful in the laboratory, and they can be used to throw

light upon some administrative problems and to solve others. But they do not make a science of administration. The very meaning of the word itself denies this effort. Administration comes from *ad* meaning "to" or "in the direction of," and *ministrare* meaning "to serve." Whatever is concerned with efforts "in the direction of serving" must be concerned with the many intricacies of personal equations. It must be, in large part, artful rather than scientific, intuitive rather than deductive, and concerned with coordination rather than with analysis.

At the same time that the case for "scientific management" was being advanced by some administrators, an inevitable backfire was being set by some professional men, who saw in these claims not only a dangerous invasion of their proper spheres of activity, but also what could become a spurious subordination of professional leadership and responsibility. Far-seeing administrators saw the same dangers and went to work to set their house in order. In the meantime, some damage was done. Fortunately, or unfortunately, as you choose to judge it, there were men on both sides who were quite capable of producing more than one *reductio ad absurdum,* or generating the kind of silly prejudice which only time and good experience can destroy.

For example, the so-called functional theory of organization was quickly and properly reduced to absurdity in establishing and administering our ship repair program and its supporting facilities during the war years 1942-1946. The error was proved to exist by professional men, but the ridicule which followed slowed down corrective efforts. In another maritime situation prejudice grew into untruth, which it took a long time to overcome. The result was a widely held view that it was administrative meddling in professional matters, and only that, which caused a very few of our World War II merchant ships to break up at sea. The calmer perspective of passing years has shown that professional ingenuity in ship repair under the stresses of war necessity added many new and permanent tools to shipyard administration. Similarly, the World War II contributions of administration to problems of ship construction have been added, I am told, to the curriculum of our schools of marine engineering.

If there ever was any doubt about the utility of competent administration in large-scale professional work, that doubt has been resolved in our generation. The professional man himself has created no small part of the need for the administrator. Since the end of World War I the all-knowing professional man has been blown by his own inventions and discoveries into a hundred specialties and as many more supporting technologies. The resulting need for integration and coordination of highly technical work has jolted the professional man out of his combination of lofty disdain of administrative problems and his most unprofessional belief that if an administrative problem cannot be ignored, its solution at best calls for nothing more than a professional conference or two.

At the same time the administrator has been getting his jolts. He has rapidly dropped smug and exclusive concern with policy and public relations, buttressed only by a few months of what he had once condescendingly called "learning the working problems." Budget, fiscal control, flow of materials, personnel policy and management, coordination of research and development with production and sales, and many other similar matters have assumed new dimensions that call for something more than manipulation of a few records and meetings of "the Board." The only difference between Government and industry in this development was that the one was spurred primarily by national crisis and the other primarily by realities of competition and profits. Feeling and reaction are much the same whether one is burned by fire or acid.

Universal recognition of the principles of specialization at both professional and administrative levels up and down the whole scale of Government activity and industrial enterprise has been most salutary. But with the end of fighting war and the economic prosperity which followed, the urgency of translating recognition into effective action, now and for the future, has not received the same attention. In science, such dramatic happenings as Sputnik gave new focus to the fact that the professional man has had to accept the need for progressive establishment of administrative units for different types of work, organized by functions, and employing experts. Unfortunately, however, the professions have tended to push aside impatiently the obvious need for greater administrative skill in handling such a development. They have tended to stick through thick and thin to the traditional concept that if the task is in engineering it can, of course, be administered by an engineer, and probably should be. If it has to do with research determinations of the nature of matter it must be administered by a chemist or possibly a physicist. If it is to organize and conduct war on an agricultural pest, its directing head must be an entomologist. Presence or absence of administrative ability and knowledge of management techniques was not very important. If there must be an administrator, other than the professional man, let him limit himself to getting money and being a buffer between professional effort and all distractions.

How great a price this attitude of mind has exacted from professional careers we can only guess. Guessing, however, is a useless waste of time unless in the process we convince ourselves, for example, that the medical profession (with some loud dissents still echoing) knew what it was talking about when it decided that properly trained non-medical administrators could run hospitals more efficiently than most doctors and nurses and

that it was, by and large, a shameful waste of medical skill to ask doctors to handle the business end of clinics. Why do I pick this example? I do so because the need for better hospital management is something almost everyone has seen for himself, and paid for into the bargain.

From the point of view of professional involvement, an equally good and more spine-tingling example is to be found in the experience of your own professions. It should be told again and again until it is as much a part of American history as the story of Robert Fulton. And its lessons should be more carefully studied by both administrators and professional men. The maritime industry, despite all its ups and downs, has made both facets of my original proposition shine.

I want to go back twenty years, a long time in the history of modern business and public administration. Because of the shortage of professionals, you used administrators early to help you do the impossible. And, more than that, you demanded that your professionals not slow their own efforts by personal lack of administrative knowledge. I pay tribute to a great accomplishment—one wrought by the greatest combination of marine architects, administrators, and engineers in all history. In 1940, Admiral Land announced that his 1937 goal of 50 merchant ships a year for ten years had been raised to a thousand in two years. The United States was not at war but if our effort succeeded, it would obviously hurt the Nazi cause. Goebbels himself took to the air in screaming derision of such a shipbuilding program, "The Americans have gone mad!" he said. "The more hopeless their goal becomes, the more grandiose their plans!"

Do you remember that by the spring of 1943 American shipyards were delivering five merchant ships a day? This was American administration and American professional competence joined in what we at the Combined Chiefs of Staff sometimes called the firm of Land, Gibbs, and Kaiser. Together, Emory Land, William Gibbs, and Henry Kaiser, with the full support of your professions, had had the courage and daring to meld administration and professional knowledge into a production miracle. Three hundred shipyards (there had been 46 in 1939) were giving a synergistic answer to Nazi propaganda about "paper ships." The Navy was accomplishing no less of a miracle in combatant ship construction, and auxiliary craft were beginning to roll off production lines like trucks. In simplest terms, your professions espoused the cause of professional-administrative teamwork. Now I ask you to become apostles for spread of the gospel, using your own experience as evidence of the truth of your message.

Rejection of the role obviously imposed on the administrator by scientific developments, as I have already indicated, resulted in an effort to make a profession and a science of administration. Profession it is in the sense that it has developed a body of specialized knowledge and techniques useful for purposes primarily concerned with the administrative process. But I repeat, administration must remain intuitive, integrative, and sensitive to all kinds of factors which usually are distracting to the professional man. Here then is a common-sense basis for collaboration, regardless of necessity imposed from without, by war, or personnel shortages.

Two small acts of self-discipline on each side will do for a start. The administrator must renounce his tendency to arbitrary and horizontal application of administrative doctrine. He must also forsake his all-too-often supercilious demand that results must be guaranteed before the professional man can be cut loose to seek success. In like manner, the professional man must cast away the robe of mystery and the mask of the witch doctor which he has so often worn in the past, and which he insults himself by wearing. He is not a charlatan like the witch doctor. He has no need of masks. They will not help to hide professional incompetence from himself, from his peers, or even from the administrator. He must also train himself not to use professional attitudes and posturing to hide administrative ignorance. If untrained in administration, he need not apologize for failure to possess skill in its techniques. His professional status is not harmed. Even momentary reflection on the previous experience of his profession and his individual experience in practicing it will reassure him that in most cases he has only to ask to be relieved of personal responsibility for administration. In other words, we must find means for obtaining better balance and less useless passing the buck between administration and the needs, opinions, attitudes, values, and perceptions of the professional man.

The professional man and the administrator must move rapidly to meet their mutual problem of successful ends through mutually complementary means, in the same way that the scientists have done in establishing requirements for interdisciplinary training and research. The whole success of a professional effort may well depend upon good administration. Where it can be supplied by an adequately trained professional man, who is available for the job, that is fine. Where it cannot be so supplied, go find an administrator who can do the job. That simple truth is self-evident to both administrator and professional man. Failure of administration, however, may destroy or dissipate the best professional work. That is not so easy for the professional man to believe or for the administrator to admit. But it, too, is true, and can be prevented by faith in the other fellow and desire to understand his problems. The way to get team effort and effective collaboration is not too hard for both sides to espouse and to follow.

First and foremost, there is the problem of communication to solve. All it takes is good will and

application. Communication with his peers and coworkers is an easy thing for the professional man. He uses a specialized vocabulary, specific in concept and substance, and scientifically precise. The administrator, too, has developed a special vocabulary, and in terms of administrative finites such, for example, as budget, fiscal control, personnel practices, and similar staff functions, it is precise. Neither vocabulary need be completely foreign to the other side. It will not be if we can only remember that the variables in almost every administrative problem are not too different from the variables in professional research, development, or production problems. There must be agreement on goals and limitations before the work begins. Furthermore, both goals and specialized vocabularies can be reduced to every-day English, with no loss to anything except snobbish vanity.

In Government, with its specialized needs, the professional man can easily obtain elementary knowledge of the Federal administrative machinery and techniques. But, I beg of you, expose him to it when he is not burdened with professional duties at the same time! In words of one syllable, "Free him; Train him; Show him; Make him use what he learns!" If there can also be inculcated in him an understanding of the mechanism and rationale of public accountability and acceptance of the assigned duties of the administrator, there will be no problem of communication on his side. The professional man, with his large capacity to store useful knowledge, can absorb these administrative vitamins in therapeutic doses, with lasting results and few undesirable side effects. If they cannot, for a few years, be built into the basic ration of his college curriculum, they can still be fed to him as a supplement to his job diet.

On the other hand, the administrator must be expected to acquire some appreciation of the scientific tradition and method used by the professions. This is a more difficult job, but it is not impossible. He, too, can be given some time for study on the job—required study. He must also be trained from the very beginning of his work experience to withhold premature administrative judgments of the professional or research worker. It will be useful for him to remember Dr. Samuel Johnson's admonition, "God, Himself, Sir, does not propose to judge man until the end of his days." Perhaps as a start on the study side, we can follow the lead of the British Civil Service. It requires its administrators working with professional activities to read and to study good biographies of scientific men of note.

The problem of communications has another aspect. Almost always the professional man is absorbed in the intellectual interest of his work for its own sake. The only competition for his attention and success that he can accept as real is the competition of others who are working on similar or identical problems. He does not want to be outdone, and that is natural. He will not be outdone, or at least not feel that he has been outdone, if he is given proper *support* (I emphasize the word support) in the organization, direction, supervision, and management of his project and the staff assigned to it, in harmony with established policy. These are jobs, by and large, for the administrator, and in doing them well he creates satisfaction for himself as well as satisfaction for his professional colleagues.

It must also be remembered that such administrative necessities as fiscal and personnel controls are anathema to most professional men when they are absorbed in other duties. If they are to administer, they should not also be professionally committed to the fullest. Furthermore, deadlines imposed by law, Congress, or public impatience can be disastrous—tragic destroyers of enthusiasm and acceptable professional urgency. A little more sympathetic insulation of professional colleagues by the administrator is not hard to achieve, and more effort to teach understanding of administrative necessities can be undertaken without overwhelming the professional man in frustration.

Acceptance of this responsibility does not mean that the administrator need be swept off his feet by worship of research, or professional zeal. Excesses of professional optimism or pessimism carry heavy administrative penalties, to say nothing of producing the most unexpected contingencies and repercussions. The good administrator knows this. He consults often; he interferes as little as may be; but he does not abdicate responsibility for keeping the effort on course.

Next in importance comes the problem of management of professional work. It, too, is an exercise in effective communication. It was long thought that most professional work could not be broken into manageable projects. It must encompass a whole. Hence it could not be managed at all except by a paragon of scientific wisdom and training who knew as much as, and preferably more than, every other professional man on the staff of the enterprise. Even the most casual look at a major assignment in electronics, medicine, engineering, physics, astronautics, or nucleonics against the backdrop of today's demands, indicates clearly that the day of such self-delusion, and also of such scientific paragons, is gone forever. As I indicated a few minutes ago, dramatic incidents have proven time and again that exploration of professional and scientific frontiers can be best accomplished one piece at a time by organized, integrated projects, utilizing such combinations of special knowledge as may be needed. Among these, of course, is good administration.

Strangely, administrative necessity, as well as the rapid advances of science, has fostered development of support technicians. Here the professional man has quickly devised effective training curricula and methods. Now the administrator must produce equally good results in devising means for insuring

that the technician is used effectively. In many fields to date he has tended to abdicate this responsibility. He and his professional colleagues need to get together across the technology board. A greater degree of mutual interdependence can be safely imposed and achieved among professional men, administrators, and technicians.

Let me illustrate. In an individual physician's office, harmony and effective collaboration between a doctor of medicine, a junior colleague, a laboratory technician, and a secretary-bookkeeper are taken for granted. The problems of administration are relatively simple. But when this common-sense arrangement and acceptance of mutual interdependence in a small-scale situation are expanded into the complexities of programs found in such a large enterprise as the National Institutes of Health, the need for more formal relationships and more coordination and management of effort become apparent. The case for using the integrative skill of the administrator is clearly seen. Fortunately, it is now accepted, and from a shaky start we are making the whole concept of the Institutes a model of administration. Analogues and extensions of this experience deserve much professional and administrative attention.

The final thought that I would leave with you is that mechanical improvements in communication have collapsed time and space. This is no longer a phenomenon. It is one of the most pressing realities of our time and its implications for administration, as well as for professional work, are infinite. We have come a long way from the complaint of George III that it was not the American patriots who had defeated his armies, but the slowness of communication. Lord Howe soberly recalled that the distance between New York and Boston prevented "administration of our success in arms." We, today, have no real concept of the reason for Pasteur's bitterness when he complained that he could not check his mistakes by mail because death moved faster than the postman.

In short, neither in professional work nor in administration can we depend upon the delay of slow communication and what my erstwhile colleague, John Macy, now Vice President of Wesleyan University, referred to as the historic luxury of delay for democratic contemplation and discussion. In furtherance of this thought Mr. Macy says:

"The range of challenges to the future manager is urgent, complex and diversified . . . It is complex in the vast interplay of interests, organizations, and personalities at all government levels from the local to the international. It is diversified in the vast array of public needs requiring attention; this array commences in the local community with urban renewal and school improvement, continues through areas of public finance, public transportation, and public welfare, and on to international affairs and space exploration.

"As a nation the United States has pressed the demand for more scientists and technicians, but national and international requirements will be more effectively filled through the develoment of more and better executives. For it is the accomplished members of this group who can blend and mesh into a coherent and unified program of action the products from a variety of professional disciplines, who can relate human effort to specified public program goals, who can marshal resources to serve public programs, and who can mediate basic differences among group interests in search of viable relationships."

I have no doubt that administrators, under the spur of having to find people to do jobs, will cut the cloth to fit the pattern in so far as they are able to do so by their own efforts. What they cannot do is to compel the cooperation of their professional colleagues. This cooperation must be freely given. It can be either the product of intellectual conviction as a matter of common sense, or the product of professional acceptance as a matter of demonstrated necessity.

Together the professional man and the administrator can do the immediate job, and, equally important, they can train individuals for leadership in the future. This training responsibility is probably the most under-estimated of all professional and executive responsibilities of senior men today. Together the professional man and the administrator can work out means of understanding and reducing to common terms the aims of management and the goals of the professions. Cooperation between the administrator and the professional man can join the many parts of our national effort into a systematic whole. Let us, in the best tradition of American democratic institutions, accept the decision and go to work.

LT. COMDR. L. L. JACKSON, JR., USN, & ENSIGN JAMES M. ROACH, USN

SUBMARINE FRAM PROGRAM WHAT AND WHY

THE AUTHORS

Lieutenant Commander L. L. Jackson, Jr., USN, was graduated from the U.S. Naval Academy, Annapolis, in 1945. He went immediately to Submarine School, New London, commencing a sea duty tour which lasted until 1951. He served in the Pacific in USS CARBONERO *(SS-377) where he qualified in submarine and participated in the beginnings of missile guidance by submarines. He served in* USS ENTEMEDOR *(SS-340) during her overhaul and inactivation at Mare Island Naval Shipyard in 1948. He ended his first sea cruise with a tour in the Atlantic in* USS CONGER *(SS-477), stationed at Balboa, Canal Zone, then at Norfolk, Va.*

In 1951 he was selected for post-graduate education in Naval Engineering (Electrical). He was graduated from the Naval Post-Graduate School, Monterey, in 1954 with a Master of Science Degree, Electrical Engineering. He commenced his second sea duty tour on board USS SABALO *(SS-302) where he qualified for command of submarines. Completing two years in* SABALO *he was assigned to the staff of Commander Submarine Squadron One as Squadron Engineer.*

Since 1957 he has been serving at Pearl Harbor Naval Shipyard, as Senior Submarine Superintendent; then Assistant Planning and Estimating Superintendent for Submarines. As Assistant P&E for Submarines he was directly involved in the planning for the FRAM overhaul of USS TIRU. *In 1958 he was selected to specialize in engineering and was designated an Engineering Duty Only officer.*

Ensign James M. Roach, Jr., USNR, graduated from the University of Notre Dame in June 1957 with a B.S. Degree in Electrical Engineering. After attending Officer Candidate School, he was commissioned in August 1958 and designated as an Engineering Duty Officer.

He was assigned to Pearl Harbor Naval Shipyard and given the job of Ship Superintendent for surface combatant ships. After six months, he was re-assigned to be Ship Superintendent for submarines.

Subsequently, he was assigned the FRAM overhaul of USS TIRU *in March 1959 and remained in that capacity until the completion of the availability. In this job, he was involved in coordinating production efforts with availability of plans, material, and manpower to assure timely completion and in acting as liaison between the Shipyard and ship's force.*

"OLD AGE OVERTAKES 80 per cent of U.S. Fleet." "Machinery break-down results in failure of Task Force to intercept enemy missile fleet." "Anti-submarine forces unable to hold contact on enemy submarine." "Own submarine loss rate double that of World War II." "Many submarines break down enroute to patrol area."

The prospects of reports such as the above and a

very real need to achieve the optimum balance between fleet readiness and availability of funds may very well have prompted the appointment of a Special Civilian Consulting Group in 1958 to inquire into and report upon the material readiness of ships of the Fleet.

On 1 January 1959 approximately 81 per cent of the total Active Fleet was composed of ships built during the World War II period. As the result of years of austere maintenance and hard usage, these World War II ships are wearing out. The designers and builders of these ships built to win a war, but not necessarily a twenty-year war. Yet these ships won World War II, then continued to operate throughout the Mediterranean Sea, the North Atlantic, the Pacific Ocean, and in other waters all over the world. They have been maintained in a high readiness for war by intense training at sea in realistic battle maneuvers. Many of these training exercises are even more demanding than were the patrols and convoys of World War II.

That these ships have withstood the demands of time and hard usage during fifteen years of constant operations is a tribute to the sailors who man them. On-board personnel allowances have been reduced again and again. The attractions of civilian life have steadily depleted the numbers of qualified officers and petty officers from the decks of the Fleet. Despite such cut-backs and losses those sailors left have kept the ships in fighting trim and running on world-wide missions. That the Fleet is in as good condition as it is today is the result of the efforts of these highly dedicated officers and men who have operated, maintained, and repaired the ships. These men are devoted to the Navy, sincerely motivated with a "can-do" spirit and well trained in methods of caring for machinery which is getting older and more worn.

Shipyards and repair activities during regular overhauls and repair availabilities restore the hull, machinery and electrical equipment on each ship to "good-as-new" condition wherever possible. But age of installed machinery, continued hard usage, and rapidly increasing costs of labor and material make such restoration more and more costly. An example is the main propulsion generator on submarines (Figure 1). Overhauling such machines normally means disassembly, thorough cleaning, dipping and baking, taking a cut on the commutator, polishing the main journals, reassembly and shop test. Such an overhaul has become more expensive due simply to increase in cost of labor. But age of the generators has made even the more expensive "normal" overhaul impracticable. Insulation in windings has deteriorated due to age. Commutators have approached minimum diameters such that they cannot be restored to roundness by taking a cut. The shafts on some types of generators are cracking and require renewal. These machines require complete rehabilitation at costs which approximate the cost of new generators.

Official U. S. Navy Photograph

Figure 1. *USS TIRU* (SS 416) View of armature windings of main generator No. 3, showing deteriorated insulation underlying slot wedges. June 1959.

Another example of an installation requiring complete rehabilitation has been the aluminum conning tower fairwater. Incident to providing snorkel capability, the lightest available fairwater was designed and installed on these World War II submarines. These aluminum fairwaters reduced drag and helped quiet noises caused by turbulence. But frequently in heavy weather large sections of aluminum would rip and break off. Deterioration of the aluminum frames and panels due to various forms of corrosive attacks weakened the structures to such an extent that failure was common. During shipyard overhauls the support, the framing and the paneling would be carefully axamined and that showing cracks or deterioration renewed. However, this work was expensive. It was not unusual to spend up to 50 per cent of the replacement cost for repairs to the fairwater. Experience in the past few years indicates that complete renewal of the conning tower fairwaters will be required after less than ten years of use. Evaluation of plastics fairwaters has shown that, despite the high initial cost, the plastic fairwater does not require expensive maintenance. Neither does it deteriorate rapidly and unexpectedly at sea. A submarine being rehabilitated and requiring extensive repair work to the aluminum conning tower fairwater is therefore fitted with a new plastic fairwater. Figure 2 shows the type installed on USS *TIRU* (SS-416).

Aging of the ships and rising costs have resulted in much higher costs for overhauling ships. As one result some Type Commanders have resorted to extending the interval between overhauls. This policy should increase the time a ship is available for operating, conserve overhaul funds, and help the Fleet continue to meet world-wide commitments without requiring additional ships. But the fiddler must be paid, and the payment is more machinery break-down at sea, more demands on the time of

Official U. S. Navy Photograph

Figure 2. *USS TIRU* (SS 416) View of plastic conning tower fairwater installed. December 1959.

ship's engineering personnel, and more costly overhaul jobs at the later overhaul.

The public is perhaps misled by the widespread news coverage of nuclear-powered submarines, high-performance aircraft carriers, guided-missile cruisers, and so forth. These ships are being built, are operating in the Fleet, and are in many cases exceeding expectations. They are undoubtedly the best in the world. However, such newsworthy ships are not today's Navy and will not be for many years to come. To balance the Soviet Navy, the U.S. Fleet consists *primarily* of World War II destroyers, cruisers, aircraft carriers, auxiliaries, and submarines. These ships have been improved and repaired at regular intervals, but not replaced. The expense of replacing them would be tremendous, just as was the building of them during World War II. Consequently these ships must be used or the size of the Fleet and the commitments of the Fleet must be reduced. But to continue using World War II ships, now rapidly approaching obsolescence, it is mandatory to rehabilitate and modernize them.

On 6 November, 1958 the report of the Special Civilian Consulting Group was submitted to the Secretary of Defense recommending that:

(1) Construction of new ships be increased.

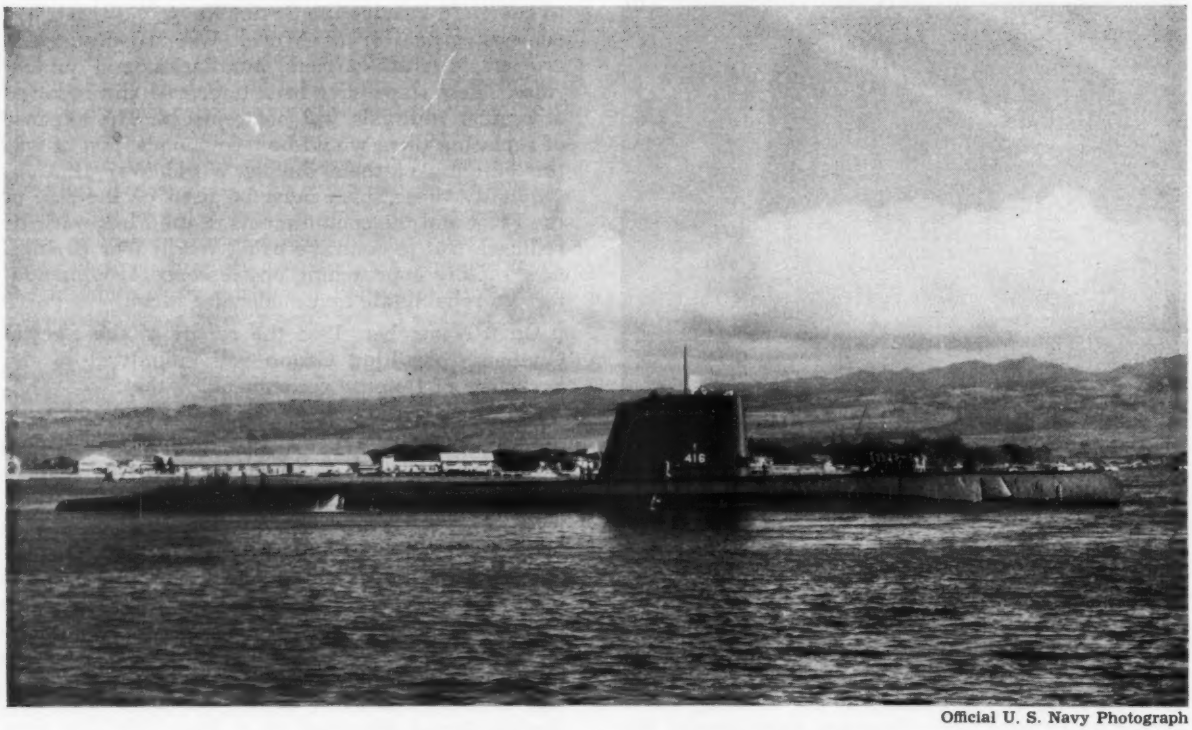
(2) Appropriate World War II ships be completely rehabilitated to forestall block obsolescence.

(3) The level of maintenance and overhaul of all ships be increased during regular shipyard availability periods.

In consonance with the second recommendation, the Chief of Naval Operations in January, 1959 directed the establishment of the Fleet Rehabilitation and Modernization (FRAM) Program. The Chief of the Bureau of Ships, then recommended USS *TIRU* (SS-416) to start the FRAM Program at Pearl Harbor Naval Shipyard on 4 May 1959, the first submarine to undergo a FRAM overhaul. Figure 3 is a Pre-FRAM view of USS *TIRU*.

Official U. S. Navy Photograph

Figure 3. *USS TIRU* (SS 416) Pre-FRAM look November 1958



Official U. S. Navy Photograph

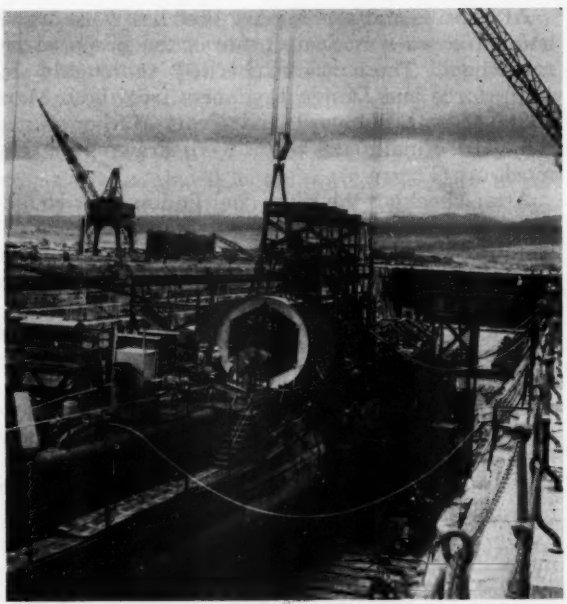
Figure 4. *USS TIRU* (SS 416) Post-FRAM look January 1960.

The Bureau of Ships exercised management, technical and financial control over the modernization of USS *TIRU*. The Planning Yard (and incidentally the original builder of *TIRU*), Mare Island Naval Shipyard, was appointed by the Bureau of Ships as the Design Agent for modernization of *TIRU*. Although separated by approximately 2,400 miles, Pearl Harbor Naval Shipyard and Mare Island Naval Shipyard were able to work closely in developing the design of the new *TIRU* (Figure 4). However, non-availability of *TIRU* for pre-overhaul shipboard checks of arrangements, dimensions, piping, and cable runs, etc., interfered to some extent with the orderly design of the new installations. Engineers and officers from Pearl Harbor Naval Shipyard, the Bureau of Ships and Commander Submarines, Pacific Fleet and *TIRU* visited Mare Island to assist in the design. In spite of the expected problems of attempting to develop new designs for a ship hundreds of miles away, Mare Island did an excellent job of design work. To reduce the number of problems in other submarines whose FRAM conversion was expected to be started soon after *TIRU*, details of the design work were freely exchanged with the Bureau of Ships, Commander Submarines, Atlantic Fleet, and other shipyards scheduled to accomplish FRAM overhauls of submarines.

The modernization aspect of FRAM for submarines lengthens the hull, thereby creating space to alleviate existing crowded conditions, and provides room for installation of modern electronic equipment. The Conning Tower is extended forward and is redesignated the Attack Center. The Radio Room is enlarged slightly and rearranged to accommodate modern radio equipment. The Forward Torpedo Room is redesigned to permit carrying additional torpedoes. A retractable communications mast is provided. In addition to these special modernization changes, existing Ship Alterations (ShipAlts) are accomplished.

The additional space for the new equipment being added (and more to be added later) was provided by inserting the new hull section near the forward bulkhead of the Control Room (Figure 5). The new section for the Conning Tower was inserted just aft the forward dome. To accomplish this work in an orderly manner, construction on the hull sections and a cradle to move the ship apart was begun in early April. Prefabricating these kept to a minimum the time that a dry dock would be required for the ship.

Cut lines were determined by Mare Island Naval Shipyard after careful study. The interference encountered and any weakening of the ship's structure had to be minimized. Once cut lines were known, work was started on the cradle. It consisted



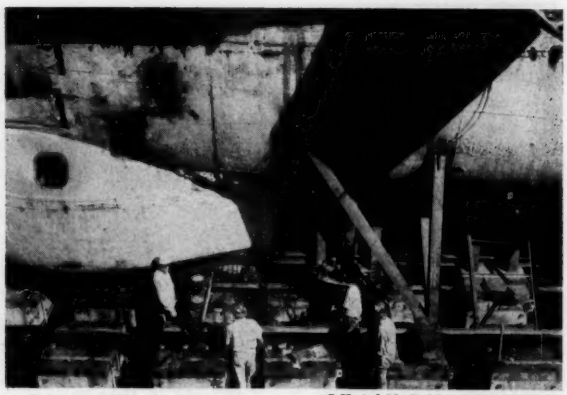
Official U. S. Navy Photograph

Figure 5. View of new 12-foot section being lowered into place.

of the normal build-up aft of *TIRU* frame 50 and a movable forward section.

Tracks were laid on the blocks, aligned and secured. These were greased to minimize friction just prior to moving of the forward section of the ship. Also, bearing shoes were made to ride on top of the rails and were coated with TEFLON to further this effect. The shoes were fastened to a web-like steel framework which took the place of the normal keel and side blocks. An abundance of bearing surfaces were provided as it was necessary to prevent any movement of the forward section of the ship while it was separated from the rest. To permit using hydraulic jacks in moving the hull section the tracks were extended aft and anchored to the after keel blocks. The jacks could then be fastened to the rails and their pressure brought to bear on the steel framework. The entire weight of the after section of the ship held the rails in place (Figure 6).

As was mentioned previously, construction on the new hull section was done concurrently with the cradle. The steel plates were first rolled in two sections and the crimped edges cut off. The edges were beveled. The sections were raised so that their longitudinal axis was vertical and then aligned. To hold the alignment and prevent distortion of the section, spider frames were attached to the section. The two pieces were welded together with longitudinal seams, as had been done in the original construction. The tank framing, flat and vertical keels, and bulkheads were added at this time. However, the outer tank hull was not added then because of



Official U. S. Navy Photograph

Figure 6. Jacking operation for moving forward section ahead.

limitations of crane handling facilities and complications of installing the hull section.

On the 4th of May 1959 *TIRU* arrived in the Shipyard and the actual overhaul began. At this point the critical work was to prepare the ship for drydocking. Removing superstructure, installing staging and removing interference in way of all cutlines had to be completed first. *TIRU* was docked on the 13th of May.

To insure that the ship would land on the blocks perfectly, transits set on the caisson and on the forward wall of the dock were used. The caisson was flooded and the dock pumped slowly so that adequate control could be kept on the ship's movements. Later when the ship was cut, the virtual absence of localized stresses proved the advantage of carefully docking the ship.

The fairwater had been removed and the interference removed in way of the Conning Tower cutline so the forward dome was easily cut off and removed. At the same time interference was being removed in way of the Engine Rooms and Battery Compartments for removal of the access patches. This was done as it was necessary to remove the main storage batteries from the ship prior to the cutting of the hull. The cut-line went through the Forward Battery Well Annex.

While the remainder of the topside interference was being removed (such as piping, main vents, and risers, valves, and cables), a one-foot section was cut from the skin of Main Ballast Tanks 2A and B. This allowed easy access to the hull itself and enabled the workmen to set up a cutting jig. A section of the keel was removed so that the cutting of the hull could be a continuous process. Parallel tracks were set up encircling the hull on the cutline. A small electric motor moved along the tracks holding the torch. Two such units were used. Having made careful advance preparation, the actual cutting operation lasted only three hours. After the cutting an additional torch was added to each unit

Official U. S. Navy Photograph

Figure 7. Cutting machine set up for beveling operation.

and the edges beveled for installation of the new hull insert (Figure 7).

Moving the forward section now could be accomplished. After some difficulty the section finally started to move. Once the teflon shoes started to bear on greased sections of the rails, movement of the section was easily accomplished. The distance the section was moved was approximately 15 feet. The total elapsed time was about 4 hours from start to finish.

The new hull section had been fabricated and only required sandblasting and prime painting. It was put on a flat bed truck and taken from the shipfitting shop to a point where a portal crane could pick it up. The crane then brought it to the dry dock where it was blasted and painted. The hull section was set in place and held while additional blocks were added for support. The forward section of the ship was then moved aft and alignment of the section with the ship began. To hold circularity, the spider frames were kept in place until the hull section had been completely welded and the framing installed.

To facilitate production welding, backing bars were used. This permitted the entire operation to be accomplished very quickly. By careful sequence welding and frequent circularity checks, the alignment of the hull section was not allowed to deviate. Inspection of the welding was done by X-raying of all seams, including those of the old structure which were adjacent to the new section.

Since the Conning Tower was to incorporate sonar plot, and in fact would be the Attack Center of the submarine, a great deal of additional equipment had to be added and a completely new arrangement was necessary. The officers at the Submarine Prospective Commanding Officers School were invited to make suggestions. Ship's force sent a representative to Mare Island Naval Shipyard to assist in the design work. Thus every effort was made to insure that operational needs would be served adequately by the new arrangement.

At Mare Island preliminary sketches were drawn and a full-scale mock-up made of the proposed arrangement. These were checked thoroughly by ship's force and Design Engineers from both Mare Island Naval Shipyard and Pearl Harbor Naval Shipyard. Finally the plans were drawn from the mock-up (Figure 8).

After checking the plans and finding that roughly 90 percent of the equipment that was to be reinstalled would be relocated, it was decided to clean out the Conning Tower completely and start again from scratch. Foundations were fabricated and installed and the few pieces of equipment that would not fit through a hatch were set in place while the Conning Tower was open.

The new Conning Tower section, like the hull section, was brought to the dry dock, blasted and prime-painted. However, in this case there was an additional problem. A trunk was to be added on the forward edge where only a hatch had been previously. Also, due to the increased number of equipments to be installed, a cable trunk had to be inserted between the Conning Tower and the Control Room. In the Conning Tower the cabling, piping, foundations, and decking were installed in that order.

Careful scheduling of shipyard trades was required in the Control Room to avoid excess crowding. There were two reasons for this: (1) The hull was cut through the nerve centers of the ship and virtually every electrical circuit and piping system had been cut thereby; and (2) The final arrangement was indefinite for the first few months of the

Official U. S. Navy Photograph

Figure 8. Full size Conning tower mock-up.

overhaul. When final arrangements became known an unusually large work force was required in this space to restore the compartments.

In order to make the Radio Room sound and light tight, the old bulkhead was removed and a new one installed. The top vertical section was left out temporarily so that it would not be necessary to re-run additional cables and pipes. This section was fitted after all piping and cabling were complete. In the case of the Sonar Room, since it was a new installation and all cable and pipe runs had been affected already, the bulkheads were built to the overhead immediately.

Since the new arrangement was radically different, it was necessary to renew cables rather than attempt to run them all over the compartment. Obsolete cable from the Control Room and Conning Tower to the Forward Torpedo Room had to be removed because of relocating the Sonar Room. Battery cables to the Forward Battery Well were renewed so that the number of splices in each cable would be limited to one.

Power supplies for the sonar equipment were to be located on the portside just aft the Forward Battery Annex Well on the lower flat. Additional berthing was provided in a similar location on the starboard side. These were new construction. Once rip-out had been completed, the reinstallation was accomplished without too much difficulty. Both spaces have sound insulation on the overhead so that men can work or sleep without being bothered by the noise of traffic above them.

Rehabilitation of existing components in *TIRU* was accomplished under the technical and financial control of Command Submarine Force Pacific Fleet (COMSUBPAC). The basic concept of rehabilitation was described by the Chief of Naval Operations as extending the life of USS *TIRU* by five years. COMSUBPAC further stipulated that *TIRU* should operate for thirty months without a major derangement which would require shipyard repairs. To achieve such a goal required careful study of each of the hundreds of systems, electrical machines, pumps, compressors, preservatives, valves, etc., installed in the ship.

As a starting point the comprehensive list of overhaul work items generated by the submarine type commanders during and since World War II was used. The detailed alteration and improvement list maintained by COMSUBPAC was added to this list. The supplemental set of repair requests prepared by USS *TIRU* was then incorporated in the list of rehabilitation work if considered generally applicable to a FRAM overhaul or treated as supplemental repair work if significant only for *TIRU*. Each of the three hundred work items resulting was carefully studied by officers and civilian technicians of Pearl Harbor Naval Shipyard, officers of the Material Section of COMSUBPAC Staff, and Engineer Officers of *TIRU*'s Division and Squadron Commanders' staffs.

To assist in this study, Pearl Harbor Naval Shipyard prepared a set of general specifications for classes of repair. This set of specifications listed all the major operations which could be accomplished on a component to rehabilitate it completely. These operations were then categorized as Class "A," "B" or "C" repair. The Class "A" job placed the component in such condition that it met its most recent equipment design and technical specification, and was essentially as good as, or better than, new. The Class "B" job restored its operating characteristics to the extent required considering its most recent specifications. The Class "C" job merely corrected deficiencies specified by a repair request. The Shipyard also prepared cost estimates for each of the three classes of repairs on all work list items where cost would be a factor. Where new equipment was available and cost of renewal was less than the cost of complete rehabilitation, cost of renewal was cited in lieu of Class "A" repair.

Shop Masters, Design Engineers, Central Planners, Shipyard Inspectors and Value Engineering personnel at Pearl Harbor Naval Shipyard were encouraged to submit their ideas for improving quality of rehabilitation. It was recognized that these individuals could contribute much toward a proper definition of the scope of rehabilitation required. Conversely, through participation in defining the work, there was generated a high degree of interest in the quality of the end result, thus assuring utmost effort at all levels to do the best job. Response of shipyard personnel was exemplary.

Having prepared a preliminary list of work items and criteria by which to classify them, a group of officers and shipyard civilians met to consider what work should be done. Primary factors for determining the extent to which each component should be rehabilitated were:

1. To what degree does the component affect sustained operation of the ship?
2. What history of failure has this component demonstrated in submarines?
3. How long can the component be expected to last considering its present condition?
4. Can ultimate savings in cost of repair be obtained by completely rehabilitating the component at this time?

As each item was classified for extent of rehabilitation, the work description was evaluated for adequacy of coverage. The standard method of repair applicable to each item was reviewed to determine whether the process met the description of work required. New materials of proven value were considered. Finally, the cost of each item was extended and the total cost computed.

To the surprise of no one the first estimate of the total cost of the rehabilitation and repair work exceeded funds available by a considerable amount.

The group met again and again, reviewing the work list and re-evaluating each item in terms of value returned for money spent. Finally, a work list was developed which could be accomplished for the funds available, yet could reasonably be expected to extend the useful life of *TIRU* by five years and provide a high degree of dependability for thirty months of operating.

The major rehabilitation work items were:

1. Provide and install a plastic conning tower fairwater designed to fit the lengthened conning tower, to accommodate the new communications mast, to accommodate a higher main induction valve and to provide a high bridge (Figure 9).

2. Provide and install a plastic superstructure from the forward edge of the plastic sail to the after torpedo room hatch, hinged to open for access to piping and valves in the superstructure (Figure 10).

3. Conduct a survey of the pressure hull and pressure systems to obtain reference readings of circularity, thickness, etc., and renew or repair any defective sections.

4. Completely re-preserve the ship using Vinyl, Saran, Devran, Dimetcote, Tarset and/or Hycon in the applications most suited for these advanced preservatives (Figure 11).

5. Replace hydraulic liquidometers with electric liquid level gages of the capacitance-type.

Official U. S. Navy Photograph

Figure 9. *USS TIRU* (SS 416) View of bridge, showing lookout ports, plastic "bubble," bearing transmitters, and communication speakers. January 1960.

Official U. S. Navy Photograph

Figure 10. *USS TIRU* (SS 416) View of plastic superstructure aft; sections partially opened. 16 November 1959.

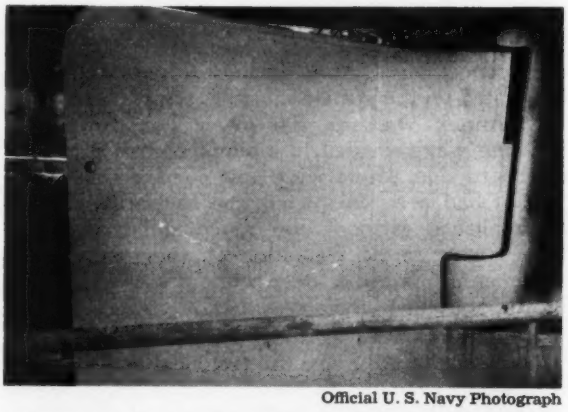


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Figure 11. An example of preservation applied—Hycon 75(Grey)—on rudder. Thickness at coating 20 mils.

6. Replace main generators with generators removed from a decommissioned submarine, and completely overhauled by the shipyard.

7. Conduct a complete inspection of all electric cabling, replacing any found defective.

8. Completely rehabilitate the main motors and main propulsion cubicle, in place.

9. Following detailed instructions received from BUSHIPS, ship's force completely overhaul all four main engines, shop facilities to be provided by Pearl Harbor Naval Shipyard.

10. Renew certain auxiliary motors, conduct Class "A" rehabilitation of some, a Class "B" overhaul of others, and ship's force using SUB BASE shop facilities overhaul the remainder.

11. Completely replace ferrous fuel oil piping with copper nickel piping.

12. Rehabilitate all electronic equipment not being renewed.

13. Rehabilitate ship's fire control system.

14. Install a director to permit firing more modern torpedoes.

15. Renew the main storage batteries.

As soon as *TIRU* was assigned to Pearl Harbor Naval Shipyard for the FRAM overhaul, action was begun to obtain material and equipment. HT steel had to be obtained for the new sections in the hull and conning tower. Contracts had to be let for the plastic sail and superstructure. Replacement components were required for those items being renewed in lieu of being rehabilitated. Delivery dates for new installations had to be ascertained to permit scheduling of work. It was readily apparent that a high priority for procurement of material was needed This priority was granted by Chief of Naval Operations in the definitive directive broadly outlining the FRAM program. The Chief, Bureau of Supplies and Accounts, issued a directive to Supply Activities emphasizing the urgency of meeting delivery dates for material. Using these directives most effectively, the Shipyard long accustomed to getting the right material on time, was able to procure material expeditiously from suppliers all over the United States.

The most interesting rehabilitation job was replacing the aluminum fairwater with the newly designed plastic one. The plastic comes in the form of a kit which contains plating and framing, door and side-light subassemblies, gussets, and deck channeling. It was inspected at the factory prior to packing and shipping. It was inspected again for flaws prior to assembly at the Shipyard.

Lines were laid out in the shop in accordance with plans and a foundation erected. The deck around the base of the fairwater was laid out and construction begun. The plastic did not have holes drilled in it for attachment to the framing. This was done using specially tipped drills and backing up the plastic so that delamination could not occur. Tolerances had to be kept to a minimum so the bolts would have a push fit. If there had been freedom left for the bolt to move, it would damage the plastic under the stress of a heavy sea.

After the shell of the fairwater was built (the decking was left out), it was sandblasted lightly. The seams between the plating joints were sealed and then the entire outside was vinyl painted. The inside was left bare to allow the ship's force to make periodic inspections for fractures or delaminations.

The fairwater was then taken to the *TIRU* and installed. The intercostals and decking were then installed on board the ship. The running-lights, accesses for electrical cables and masts, foundations for bridge equipment, ladders, and safety rails followed as practicable.

The superstructure, like the fairwater, was to be made of plastic. Where the fairwater had been bolted plastic-to-plastic, here the plastic was to be bolted to metal framing. To keep from pulling the plastic to conform with slight irregularities of the metal and to protect the metal surfaces, the metal surface was shimmed with fiberglass sheets impregnated with epoxy resin.

The design of the superstructure is such that it is hinged in sections. This allows for periodic inspection or repair of topside piping and valves. To do this, three major features were incorporated: (1) hinges just above the tank tops and padeyes along centerline; (2) short sections approximately 10 feet long of limited weight so that a portable boom and chain-fall could lift each easily; and (3) bolted method of securing the sections so that they could be loosened from topside and yet be solid when tightened down. This feature of accessibility to topside gear was to be tested many times before the end of the overhaul and proved itself to be a great asset.

Other rehabilitation work included all the major equipment the ship carried. Main generators were taken out, opened and inspected. It was found they needed major repairs. Generators that had been completely overhauled were removed from a decommissioned submarine, cleaned, checked, and installed on the *TIRU*. Only the generator coolers were found to be in need of repairs. Three of these were repaired and the remainder were renewed.

The four main engines were removed from the ship and their overhaul accomplished by ship's force. Along with the engines, ship's force overhauled the high-pressure air compressors and a multitude of the smaller and less intricate equipment on the ship. Most of these units the shipyard removed, reinstalled and furnished assistance for work that was beyond the capacity of ship's force. The outstanding work done by ship's force on these units in the limited time they had available was a major factor in the timely completion of the overhaul.

Auxiliary motors, such as Interior Communications Motor Generator sets, supply and exhaust blower motors, and hydraulic pump motors were removed and completely rebuilt. Others such as trim and drain pump motors, and high-pressure air compressor motors were replaced with new ones.

As soon as the *TIRU* was put in dry dock a partial hull survey was made. On the basis of the findings, many of the crown frames were removed and new ones installed. Some of the tank framing and plating were renewed. A section of each of the engine room patches had to be renewed.

Preservation of metal surfaces on a submarine has been a major problem for years. In keeping with the FRAM program, the most modern applications were used on the *TIRU*. All of the bilges were completely cleaned and coated with a coal tar epoxy. This was done in the middle of the overhaul when the ship was empty. Devran was used in tanks that held sea water most of the time. Dimetcote was applied in the normal fuel oil tanks and in the snorkel

induction piping. Due to the extensive nature of the work, the topside areas were completely sandblasted and painted with the vinyl system to insure as complete protection as possible. Since the underwater hull paint work was in fairly good shape, it was only necessary to brush blast it, feather the edges, build up the thickness and apply antifouling coats.

Starting in August of 1959 and continuing through October, the patches were welded back on the ship. This customarily marks the beginning of the end of an overhaul. Installation was staggered so that the reinstallation of equipment could take place in an orderly manner. The first patch to be reinstalled was the After Engine Room patch in mid-August. In the first half of September the Forward Engine Room patch was welded in place.

About this time the ship was scaled, sandblasted, and painted externally. Then the outboard exhaust valves, vents, vent risers, piping, mufflers, main air induction valve, snorkel valves, etc., were brought to the dry dock and installed. The underwater work, such as touch-up painting, adjustment of valves, test of tanks, etc., was approaching the final stages.

On September 26 installation of the new main storage batteries began. By October 10th this work was essentially complete with the platform deck back in place. All battery access patches except the Control Room had been installed and checked by X-raying.

On October 8th the *TIRU* was undocked. From this point on it was necessary to decrease manning level on the day shift and increase it on the night and graveyard shifts due to space limitations in the boat. This was the time in the overhaul when every cubic foot in the boat seemed filled by someone wanting to bolt up a flange, bolt onto a foundation, run a cable, or connect some wires. And for every mechanic that finished there seemed to be another ready to take his place day or night.

With *TIRU* afloat it became possible to start shipboard tests of some equipment. By the middle of October the ship was able to use its own systems to furnish AC and DC power, thus eliminating a large number of additional cables running through the ship. At this time the running-in and testing of the main engines and generators began. On 1 November the first battery charge was conducted using all ship's equipment except air flow meters and hydrogen detectors. These were supplied by the shipyard.

In the first week of November the new sonar gear arrived. This was the last of the major equipments to be put in the ship. The COC patch was installed then. About this time the fairwater and superstructure fabrication was finished and these were installed.

With repairs and check-out of the main-propulsion cubicle finished main propulsion trials were started in mid-November. Since there were so many pieces of equipment to be tested prior to sea trials, the testing of equipment was done as it became ready. If check-out was done by 8:00 in the evening, the testing started immediately. If there were any discrepancies corrective work commenced the same shift.

Harbor trials were next on the agenda. They revealed many defects that had not been apparent until the ship was isolated from shore connections.

The day prior to first sea trial *TIRU* was inclined to check ballast loading. The preliminary indications showed she was light aft. These indications were confirmed the following day on the trim dive. She was redocked and ballast added in main ballast tanks 6C and D. The data obtained as a result of the inclining now serves as a reference for any future weight changes that might be made in the ship.

After undocking all equipment was rechecked and made ready for the second sea trial. On this trial a test depth dive was made. The test was completed nicely and the end of the overhaul was clearly in sight. On 31 December 1959 the FRAM availability for *TIRU* was completed.

By modernizing this submarine, the U.S. Navy in an eight-month availability obtained a submarine with greatly improved reliability, increased range, major improvement in habitability, increased capacity for detecting snorkeling submarines and successfully attacking them, and vast improvement in ability to communicate. With the extension of the pressure hull, the metacentric height was raised and space made available. This will permit the adding of newer and more exotic equipment without fear of making the submarine unstable or crowding out the people.

These advantages (which were gained for *TIRU* by the investment of less than three times what it would have cost to give her a regular overhaul) are being obtained for a selected number of U.S. submarines and destroyers. It will definitely forestall block obsolescence of these types in the Navy. Of most importance, it will give the U.S. Navy a much better chance with the more modern Soviet Bloc Navy between now and the day the U.S. Fleets will be replaced completely with nuclear-propelled, fully automated, multi-environment ships.

"THE SHIPBUILDER AND MARINE ENGINE-BUILDER"

TECHNICAL PROGRESS IN MARINE ENGINEERING DURING 1959

ACKNOWLEDGMENT

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DIESEL ENGINES

In March, 1957, Mr. C. C. Pounder, technical director of Messrs. Harland & Wolff, Ltd., Belfast, drew attention to the complete practicability of successfully constructing engines of the orders of 880 mm bore which, on a conservative rating, would be capable of developing 2,500 bhp per cylinder. The forecast is beginning to be fulfilled and such engines are now being constructed in Italy, Denmark, and Switzerland.

Fiat Grandi Motori, Turin, announce that 2,650 bhp per cylinder has been developed in a two-cylinder experimental engine of 900 mm bore by 1,600 mm stroke, to be the forerunner of a nine-cylinder engine of the same bore and stroke for a service output of 18,000 shp. This engine has been ordered by Achille Lauro, Naples, for a tanker of 38,000 tons at present under construction.

The new Burmeister & Wain engine, with a bore of 840 mm and a stroke of 1,800 mm has an output of 2,000 bhp per cylinder. This was established while running the shop trials of a six-cylinder engine intended for a tanker of 19,000 tons, the contract output required being 10,400 bhp. On test it was demonstrated that higher outputs were safely possible and it was subsequently given a continuous service rating of 2,100 bhp per cylinder at 110 rpm with an m.i.p. of 135 psi and specific fuel consumption of 0.347 lb./bhp-hr. Under such conditions, and with a maximum pressure of 924 psi, thermo-couple measurements indicated that the inside temperature of cylinder covers, liners and piston crowns are about the same as in the smaller turbo-charged B. & W. engines running at normal full load. Like these smaller engines, the new unit—the 84-VTBF-180—is of the two-stroke crosshead type with timed exhaust valve in the cylinder head. It can be either constructed in cast iron or fabricated of welded steel. The gas forces are transmitted through tie bolts from the top of the scavenge air box to the underside of the bedplate cross girders. The double bottom of the scavenge air receiver is intended to prevent the possibility of a fire in the receiver causing a crankcase explosion. The camshaft and the engine are designed with a view to simplifying maintenance and it is said to be possible to withdraw, overhaul and refit pistons in about three hours. The pistons are of chrome molybdenum steel; each has a bolted-on carrying ring and welded-in cast-iron wear rings on the piston ring lands. The engine tested, *i.e.*, of maximum continuous rating of 12,600 bhp, has a total weight of 470 tons. A 12-cylinder engine, having a service output of 25,000 bhp will have a length of 72.5 ft and a weight of about 885 tons.

An order has recently been placed with Messrs. Sulzer Brothers, Ltd., Winterthur, by Koninklijke

Rotterdamsche Loyd N.V., Rotterdam, for a six-cylinder engine of 900 mm bore developing 11,015 bhp, *i.e.*, 1,835 bhp per cylinder.

The most powerful Diesel engine so far constructed in the United Kingdom is the Stephen-Sulzer 12-cylinder engine built by Messrs. Alexander Stephens & Sons, Ltd., Linthouse, Glasgow, and fitted in the motorship *City of Melbourne*. It is but moderately rated at 14,000 bhp at 114.5 rpm. On the test bed this set developed 18,220 bhp at 126 rpm with a bmep of 111 psi. The bore and stroke are 760 mm and 1,550 mm respectively, and four Sulzer, type RT67, exhaust-gas turbo-chargers are fitted. Scavenge pumps are omitted and the under-piston compression effect gives adequate scavenging for starting requirements. A Holset damper, fitted at the forward end of the crankshaft, effectively reduces torsional vibration stresses so that there is no barred speed range. The total weight is 720 tons and the overall length is 72 feet.

During the year, Messrs. William Doxford & Sons (Engineers), Ltd., Sunderland, have installed in the oil-tank ship *Corhampton*, of 20,000 tons, their first opposed-piston engine built without engine-driven scavenge pumps. It has six cylinders of 700 mm bore and a combined stroke of 2,320 mm. The service rated output is 10,450 bhp at 120 rpm with an mip of 116 psi. Two Brown-Boveri VTR630 turbo chargers normally supply the air, but to augment the supply under slow-running conditions two electrically-driven fans are provided (manually controlled Davidson units); they also act as standby capacity in case of a main blower failure. The overall length is 57 feet 7 inches, height 33 feet 3 inches, bedplate width 12 feet 4¾ inches, and weight 480 tons.

A more advanced design has also been prepared and is being built for test with a cylinder bore of 670 mm and a combined stroke of 2,100 mm. With normal aspiration the engine will develop 1,300 bhp per cylinder and 1,800 bhp per cylinder when turbo charged. The crankshaft has been shortened and stiffened by reducing the length of the bearings and increasing their diameter and spherical bearings have been eliminated. The ratio of the throw of the side cranks to that of the center crank has been chosen to give reciprocating balance, rotary balance being achieved by using counterweights on the center webs. This has resulted in a reduced throw for the side cranks which, together with increased diameter of main bearings, has increased the stiffness and consequently, the natural frequency for both torsional and axial vibration to such an extent that no detuner will be necessary for engines of less than six cylinders, and engines with more cylinders become possible. The crankshaft is in two pieces joined by a large diameter rigid coupling. Center and side crossheads are of a simplified design. To minimize top end troubles a pad has been placed on the connecting rod directly under the piston rod to take some of the load directly and reduce the load on the side bearings. The upper and lower cylinder liners are clamped by means of their corresponding water jackets to a central cast-steel combustion chamber section. For the normally-aspirated engine, lever driven scavenge pumps are dispensed with and the drive is taken directly from the side cross-heads, while on the turbo-charged engine, there will be no scavenge pumps at all.

Messrs. Ruston & Hornsby, Ltd., Lincoln, have introduced the AT series of turbo-charged, four-stroke cycle engine, having five, six, seven, eight and nine cylinders of 12½ inch bore by 14½ inch stroke; the marine version ranges for 622 to 1,120 recommended continuous shp at 500 rpm without intercooler; the corresponding figures with intercooler being 793 to 1,420 shp. So successful has been the design that the fuel consumption of prototype models is 0.34 lb./bhp-hr. The design of all important components has been studied fundamentally; investigation of stress distribution showed that four bolts of improved design could safely be used for attaching the cylinder heads in place of the seven previously used, and models used to investigate bearing deflection have led to a stiffer bearing of simpler form. The steel crankshaft is forged by the continuous grain-flow process and the distribution of counter-weights, together with the effect of a Metalastik coupling is such that the need for torsional vibration dampers is eliminated. A high level camshaft dispenses with push rods and is chain driven, the tension of which can be adjusted without disturbing the timing. In intercooled engines, the cast-iron cylinders are oil-cooled and at 500 rpm the bmep is 160 psi. The pressure drop across the intercooler is 0.5 inch Hg (from 17.8 to 17.3 inch Hg) and the temperature drop is from 183 to 93° F.

AUXILIARY GEAR

Centrifugal Purifiers

The subject of "Centrifugal Purification of Oils for Marine Service" is dealt with by Mr. M. E. O'K. Trowbridge, B.Sc., A.C.G.I., in his paper to the Institute of Marine Engineers; Oct, 1959. The development of centrifuge types suitable for the purification of fuel oils and lubricating oils on board ship is traced from the batch units manually cleaned, through semi-continuous units, both mechanically and automatically cleaned, to the recently developed Gravitrol type of fully-continuous centrifuge.

In essence the Gravitrol appears to be similar to a clarifier recycle nozzle centrifuge, however the recycle dam system is proportioned so that the bowl only accepts sufficient recycle water to maintain the oil/water interface at its desired position outside the disc stack. Under actual operating conditions, oils of varying specific gravity may be fed to the centrifuge tending to alter the interface position. This is counteracted by varying the temperature of the recycle water stream so that its specific gravity is

varied in step with that of the oil feed and there is no need to stop the machine and change the ring dam. This system seems to be especially well suited to single-stage purification of heavy fuel for Diesel machinery, including washing if required, to gas turbine fuel oil washing and to lubricating oil purification for both Diesel engines and steam turbines.

A most important section of the paper considers the assessment of separational capacity of a centrifuge. It is pointed out that the centrifuges used for marine oil purification are classifiers and as such will remove finer and finer particles, the lower the throughput; thus, when considering centrifuge capacity, it is important to specify the degree of purification required for the proposed oil being treated. Unfortunately, if the specification is written in this way, the normal user is not able to confirm that his requirements are, in fact, being met. On the other hand a specification such as:—"A centrifuge to purify 1½ tons per hour of fuel oil of 3.000 seconds Redwood No. 1 viscosity," is not sufficiently precise. It is for this reason that the meaning and the derivation of the Σ value is explained. From first principles it is shown that in order to achieve any particular degree of purification with a centrifuge, the rate of flow of liquid through the bowl is directly proportional to the product of two parameters, one of which characterizes the solid/liquid system being handled, the other depending solely on the geometry and speed of the bowl. This latter is termed the Σ value and for a given degree of purification with a given liquid/solid system it is an index of the capacity of the centrifuge. Using this concept, the performance of various centrifuges can be compared from a knowledge of the geometry of the various bowls and their speeds of rotation; since, to perform a given degree of purification, on a given oil, the capacity at which this can be achieved is directly proportional to the Σ value.

The author indicates a recent interesting development for purifying lubricating oil by passing the full flow through an hydraulic cyclone, the main overflow circulating to the bearings and the underflow (in which dirt and water is concentrated) passing on to the centrifugal purifier. The cyclone acts as an unblockable coarse strainer giving full flow purifying effect at the coarser end of particle size range and considerably improves the effectiveness of lubricating oil purification for comparatively small additional cost.

Finally, the paper includes a brief discussion of the pretreatment of oils before centrifuging, with particular reference to the neutralization of acids present.

Heat Exchangers

There have recently been several successful applications of the De Laval plate heat exchanger as a replacement for shell and tube types. Such plate coolers basically consist of a number of standard shaped plates which separate the heat exchange fluids into thin layers flowing in opposite directions. The construction is thus very flexible. The number of pairs of plates can be varied and paths can be arranged in series or in parallel so that a wide range of temperature, capacity and pressure-drop can be handled.

Distilling Plant

Multi-stage flash evaporators for use at sea have been recently developed by Messrs. Buckley & Taylor, Ltd., Oldham. Each stage comprises a flash chamber, at the top of which is a nest of tubes acting as a vapor condenser. The raw sea water feed is passed through the vapor condenser of the lowest pressure stage and then successively through each vapor condenser in order of ascending pressure. This preheated feed then picks up further heat in a primary heat exchanger after which it passes into the flash chamber associated with the last vapor condenser. Some of the heated sea water flashes off into vapor and the remaining sea water passes down to the next flash chamber (at a lower pressure still) where some more vapor is flashed off, and so on down to the last flash vessel where the slightly concentrated brine is pumped away to waste.

A Danish firm, Nirex Engineers, Ltd., Copenhagen, have developed a single-stage flash evaporator which utilizes waste heat from a Diesel engine, but in this case, the engine cooling water is itself distilled. The same firm have also developed a steam-heated evaporator designed for the falling film condensation of the steam on the outside of a vertical nest of tubes. It makes a very compact unit housed within a single shell.

If the condensation temperature of the made vapor is below 160° F. the fresh-water must be suitably treated to destroy all bacteria before it is fit for human consumption.

Self-regulating Marine Alternator

A self-regulating alternator has been developed by Messrs. W. H. Allen, Sons & Co., Ltd., Bedford, to meet the requirements of accepting the relatively high starting currents of large squirrel-cage induction motors without causing a heavy voltage drop over an appreciable period. The new alternator is a combination of the proved Allen marine unit and a completely static excitation and regulating system. A major break with conventional design is the replacement of the shunt-wound d-c exciter by a static excitation system of transformers and rectifiers in which shunt and series elements are combined to produce an alternator field current approximately similar to that required for normal voltage. A static automatic trimming regulator maintains the degree of voltage steadiness required

for marine work. The basic operational principle of the alternator is that of phase-compensated line current compounding together with static self-excitation.

Cargo-handling Gear

A series of comparative cargo-handling tests have been carried out between shipboard cranes and burtoning gear using conventional derricks and winches for the Maritime Administration Department of the United States Department of Commerce and the results are published in their Report No. P.B.121920 R. Special controlled tests were used in the comparison, as well as tests carried out during normal cargo-handling operations. A summary of the controlled tests is given and it is claimed that they yield valid results and have the advantage of taking much less time than service tests. The results of both service tests and special controlled tests were found to support the same conclusions.

The equipment used was the five 5-ton cranes fitted to the motorship *Thomas Nelson,* of which the three forward ones have electro-hydraulic control and drive and are mounted on transverse tracks, the two after cranes having electro-mechanical control and drive and are mounted on longitudinal tracks. Also the modified 10-ton derricks which had replaced the original 5-ton units on the steamship *Benjamin Chew* (steam winches); standard electric winches and derricks as fitted to the steamship *Southport,* a C-2 cargo ship. The *Benjamin Chew* and *Thomas Nelson* are modified Liberty ships.

With one class of cargo which included ferrous products, boxes, baled and bagged goods, cranes gave up to 15 per cent improvement over conventional gear when their "spotting" ability could be used to reduce manual horizontal movement in the hold. When able to use their ability for direct vertical positioning, cranes gave a loading rate up to 100 per cent greater than with conventional equipment. When the speed of operation was limited by the work required within the hold, or where the "spotting" ability of the crane could not be exploited, there was little difference between the two types of gear. There was little significant difference between the two types of crane on the *Thomas Nelson,* although the effect of the position of No. 3 forward crane (very close to the centercastle) sometimes induced a performance loss of up to 20 per cent, but it could be used more efficiently when limited to cargoes for which the speed of hook transit was of secondary importance.

Refrigeration and Air-conditioning

Present-day types of refrigeration compressors are high-speed multi-cylinder types, having from 2 to 16 cylinders arranged in vee or radially. Regulation by speed variation is not so common since the introduction of alternating current on board, and it is now often obtained by decompression of one or several cylinders. It is understood that centrifugal compressors are developed for applications such as air-conditioning which requires high refrigerating power with comparatively small variation between high and low-pressure. An oscillating electro-magnetic compressor, with the piston driven by a vibrator is considered to be a very robust and likely proposition.

A paper dealing with "The Development of Air-conditioning in Ships," was presented by Mr. S. J. J. Jones, B.Sc., and Mr. J. K. W. MacVicar before a joint meeting of the Institute of Marine Engineers and the Institution of Naval Architects in January, 1959. The authors indicated that in vessels with large air-conditioning loads, the centrifugal compressors are likely to be driven by electric motors rather than steam turbines, and that a direct expansion system may supersede the present intermediary use of brine circulation, provided that satisfactory distribution of refrigerant, together with means of local control, can be obtained. The use of plastic ducting for branch duct systems, dispensing with the necessity for duct insulation is receiving considerable attention. Where large quantities of condensate are recovered from air-conditioning units it could well be used as boiler-feed make up.

An interesting new German plastic material, called Isochaum has been reported in *Hansa* during the year. It is an insulator, the components being mixed in a portable mixer and then directly sprayed on to the desired surface through a plastic hose. Thus normally inaccessible surfaces or cavities can be dealt with. It sets after a few minutes and is dry in about 24 hours. Its density is 0.62 lb per cu ft and it can be used between $-328°$ F and $+ 428°$ F. At 428° F it decomposes, but the resulting gases do not explode or burn when in contact with flame.

STEAM TURBINES AND BOILERS

A review of the advances in the design and construction of steam turbines for ships is made by Mr. A. D. Somes in the paper entitled "Advances in Steam Turbines for Marine Propulsion," presented to the Institute of Marine Engineers in March, 1959. The paper is based generally on the experience of the General Electric Company. Data curves are given on the effect of increase of initial steam pressure and temperature with increase of power per shaft on specific fuel consumption. The effect of monetary inflation is mentioned and its importance in relation to anticipated rise of fuel cost and costs of repair during the life of the ship is pointed out. The author considers that metallurgical advances together with improved design techniques made possible by intelligent use of digital computers to solve complex analytical problems, have resulted in

the maintenance of the same standard of reliability for turbines with advanced initial conditions as for those older sets of more conservative design. Many details of design are discussed and the effect of increasing temperature is examined; the abandonment of reaction type turbines in favor of all-impulse is forecast. Excellence of operating characteristics can be assessed in terms of low amplitudes of vibration and minimum response to unbalance. This places the first critical speed of the rotors operating in the assembled turbine within the running range, but this has not been found to affect reliability in service; on the contrary there is considerable indication that reduced stiffness of the rotor increases its tolerance to abnormal conditions, and there is little advantage to be gained from a draft design which puts the first critical on rigid bearings above the running range. Spring backed packings throughout, relief grooves in the shaft at the ends of the packings and shaft proportions that place the critical speed at a lower point are the important criteria.

As deadweight increases, the current trend in large tanker machinery is towards successively higher torque on the propeller shaft. In connection with problems associated with the gearing to be used for such high torques, Mr. J. R. G. Braddyll, B.Sc., and Mr. M. C. Oldham, F.I.M., presented a paper on "High-torque Merchant-ship Gearing," before the North-East Coast Institution of Engineers and Shipbuilders. In the paper, machinery developing 26,500 shp at 109 rpm is taken as an example and three proposals for gearing are examined. Proposal "A" embodies conventional gear materials, En.26 for pinions and En.9 for wheels, the tooth loading being in accordance with Lloyd's Rules, and K factor being 100 and 90 on the first and second reduction gears respectively. Proposal "B" incorporates the same second reduction gears as proposal "A" (K = 90), but the first reduction gears are hardened and ground with a K factor of 275. Proposal "C" employs a duel tandem gear configuration. The second reduction gears are the same as for proposals "A" and "B" and designed on the same loading factor (K = 90). The first reduction gears are hardened and ground the K factor being 250.

A paper on "Heavy Oil Burning" was presented to the Institute of Marine Engineers during the year by Mr. J. S. Clarke, O.B.E., Ph.D., and Mr. G. J. Hudson, M.A. The properties of various fuels are considered with special reference to the requirements of fuel injection and the different methods of fuel atomization. Other sections deal with evaporation and burning times, carbon deposition, aerodynamic requirements of flame stabilization and flow pattern development particularly in the primary zone. The special problems of design and performance of register equipment (with open flame) and combustor equipment (with enclosed flame) are treated separately.

The British Shipbuilding Research Association and the British Ceramic Research Association have been carrying out, for some years, a joint program of research aimed at improving the life of furnace brickwork in marine water-tube boilers. The results of a series of tests carried out on a number of modern water-tube boilers with the object of determining the refractory hot-face temperatures under service conditions are reported in the paper presented before the Institute of Marine Engineers in April, 1959, by Mr. W. McClimont, B.Sc., Mr. H. M. Richardson, B.Sc., and Mr. Bryan Taylor, B.Sc. (Eng.), entitled "Boiler Refractories: Operating Temperatures and Recent Developments in Construction." Continuous records were taken under service conditions, to measure rates of change of temperature, as well as maximum steady temperatures. The various factors that influence the operating temperature of a furnace lining are considered from a theoretical viewpoint and comparisons are made with test results. These latter indicate that the degree of perfection of combustion—a matter of design and operation of combustion equipment—have a marked effect on brickwork temperature.

Uniformity in the methods of performing boiler-water tests and in expression of results is very desirable, but even more desirable is simplicity of method of testing, especially where control tests are to be carried out by operators having no special skill or training in chemical manipulation.

A series of standard sized tablets has been developed by Dr. A. T. Palin, which, with one or two exceptions, combine all the reagents for any particular test in a single tablet, together with indicators and, in addition, suitable foaming agents are included to assist in observing color changes at the end points in dirty or discolored samples—they give the effect of color absorption in the foam layer.

The general procedure for all tests consists in adding the tablets to the sample one at a time until the required color change is obtained. The tablets are self-disintegrating and do not require crushing. It is claimed that this system of boiler-water control tests is unsurpassed for simplicity and thus there is every encouragement to the maintenance of regular routine testing. The great advantage of this system is that it dispenses with the need for expensive chemical apparatus, glassware, standard chemical and indicator solutions, and enables a complete testing kit to be reduced to small bulk, requiring only a stoppered bottle for shaking the sample, preferably marked in 50 ml, 100 ml and 200 ml (otherwise use measure) and the bottle of test tablets.

Prevention of corrosion of metal surfaces in contact with boiler water depends primarily on the removal of oxygen and carbon dioxide from the water. Oxygen can be readily reduced to a neg-

ligible value, but carbon dioxide presents greater difficulty. The addition of caustic soda to the boiler water takes care of the boiler, but as it is not volatile it affords no protection to the remainder of the system. Cyclohexylamine, however, is a volatile alkaline compound which combines with carbon dioxide to form a non-corrosive amine bicarbonate, and it is becoming widely used for this purpose. In an article on "Cyclohexylamine for Corrosion Prevention in Steam Raising Equipment," in *Corrosion Technology*, March, 1959, the authors, Mr. W. K. Ashcroft and Mr. P. N. Heron, describe in detail the mechanism of this type of corrosion of ferrous metals and copper, and the practical considerations involved in the use of cyclohexylamine to prevent it.

"Experiences with Cyclohexylamine in the Condensate Feed-water Systems of High-pressure Boilers," by Mr. I. B. Dick and Mr. C. P. Fritz (A.S.M.E. Paper No. 58-A-263; December, 1958), contains a report of service experience with cyclohexylamine treatment of feed-water in two 900 psi boilers (five years), two 1,750 psi boilers (one year), and one 2,020 psi boiler (six months). The results as presented in graphical and tabular form. It was found that cyclohexylamine additions to boilers which had already been operating for some years, succeeded in reducing the iron and copper concentrations in feed-water within six months, but that improvement in boiler cleanliness did not visually appear for three years and was not pronounced even after five years. Since no harmful results were experienced and the costs of the treatment are very small it was decided that the treatment should continue.

"Limitations on Chemical Means of Controlling Corrosion in Boilers," by Mr. D. E. Noll (*Corrosion*, November 1958), shows that the relationship between temperature and corrosion is complex and the author points out that the corrosion mechanism may differ at different temperatures. This relationship has been extensively investigated recently in connection with prevention of corrosion in the primary loop of pressurized-water nuclear-power plants.

NUCLEAR POWER

On the 5th May, 1959, the Admiralty announced that an urgent examination would be made of eight designs (which had been submitted independently from eight sources) of reactors for Britain's first nuclear-powered merchant ship. Not all the designs are equally advanced for early use, and their merits are being assessed by a technical sub-committee set up by the Civil Lords Committee. It is to be hoped that the report will soon be forthcoming, as from its recommendations it will be possible to judge which system offers the greatest advantages, balanced against the time it would take to put the various systems into operation. Meantime, the main committee has been examining ways of financing the first ship. The Ministry of Transport Committee on Marine Nuclear Safety is continuing its work already begun on the problems of safety in nuclear-powered ships themselves and in the ports and harbors in which they will follow their trade.

Table I. compares some features of the various designs.

Method of Conversion

In view of the uncertainty of the time which is likely to elapse between the decision to install, and

TABLE I

Manufacturer, Reactor and Type	Power of Turbines, shp	Steam Conditions		Total Weight, Tons	Fuel Enrichment
		psi	°F.		
A.E.I.—John Thompson; Boiling water	(82 MW) 26,000	1,000	546	1,600	2.1 per cent
Babcox-Wilcox; Pressurized water	(180 MW) 65,000	410	447	3,000	2 to 4 per cent
De Havilland; High-temperature gas-cooled (Helium) graphite moderated	(150 MW) 45,000	600	850	2,400	U.235 plus thorium.
G.E.C.-Simon Carves; CO_2 cooled graphite moderated	(150 MW) 45,000	600	850	2,400	slightly enriched.
Hawker-Siddeley; Terphenyl as organic moderator/coolant	(56 MW) 17,000	480	710	1,300	1.4 per cent
Mitchell-Fairfield Combustion Engineering; boiling water	(156 MW) 50,000	650	496	3,000	2.55 per cent
Vickers Nuclear Engineering; heavy-water moderated cooled, dry steam	(160 MW) 50,000	420	850	2,100	1.7 per cent
United Kingdom Atomic Energy Authority;			no details		

the actual manufacture of a particular marine type reactor (other than a pressurized-water reactor), the scheme for the conversion of an existing suitable ship proposed by the Isbrandtsen Co., Inc., is of considerable interest. They are planning to build a hull section corresponding to a cargo-tank section of the *Hans Isbrandtsen* class (a tanker of 32,790 tons deadweight) and in it to install a reactor. This will be tested, and when a satisfactory performance has been achieved, the whole section will be substituted for an existing section of the ship.

The proposed reactor is to be graphite moderated, helium cooled and will be fueled with uranium dioxide pellets clad in stainless steel. The exit gas temperature will be 950° F and steam will be generated at 640 psi and 850° F—a condition suitable for the existing propulsion machinery. As the coolant is inert and at relatively low pressure and temperature, comparatively simple materials and metallurgical techniques can be used. The reactor system is expected to be ready for sea trials in about three years time.

A paper entitled "Some Metallurgical Features of Nuclear Reactors," by Mr. H. M. Finniston, appears in the Transactions of the Joint Panel on Marine Propulsion, 1959. The author gives background metallurgical data on three general features of interest to the reactor designer of any system, *viz.*, the fuel element, the pressure containing vessel, and corrosion. The effects of irradiation on the reactor materials are considered in some detail, together with fabrication and corrosion behavior in various coolants.

"Some Aspects of Marine Safety," by Mr. K. Maddocks, Joint Panel on Nuclear Marine Propulsion, 1959, demonstrates that two of the main factors influencing the choice of a reactor system for commercial marine propulsion are safety and economy. The object of this paper is to emphasize the paramount importance of the former in examining the engineering problems which influence design. References are given to the official views on the hazard from the biological effect of ionizing radiation, and on tolerable doses. The author also gives references indicating a comprehensive literature covering the rudiments and application of shield design techniques.

GAS TURBINES

During the year, three British gas-turbine installations have gone to sea in the *Morar*, the *Goodwood* and the *Auris*, while a few details of operating results have been published of the two American installations already at sea in the *William Patterson* and the *John Sergeant*.

G.T.S. "Morar"

The propelling machinery consists of an exhaust-gas turbine geared through normal reduction gearing to the propeller shaft, the exhaust gas being provided by three G.S.34 gasifiers manufactured by the Free Piston Engine Co., Ltd., Feltham, Middlesex, under license from Messrs. Alan Muntz & Co., Ltd., also of Feltham, Middlesex. The normal power requirement for the vessel is 2,500 shp, the normal service fuel being 1,500 seconds Redwood No. 1, at 100° F. The double-casing turbine has been designed by Power Jets (Research and Development), Ltd., London; it has six ahead stages and two astern stages on the same shaft with separate inlets and a common exhaust. Successive wheels are spigotted together near the periphery to build up the ahead rotor, to which is then attached a smaller diameter forged drum carrying the two astern rows; the whole assembly is held together by a central through bolt. Both ahead and astern volutes have two inlets and the exhaust end of the astern stages is provided with a deflector plate to reduce so far as possible the circulation of exhaust gas within the astern blading while the machine is running ahead.

The G.T.S. *Morar* has a sister ship, the motor vessel *Orecrest*, which is propelled by orthodox directly-coupled Diesel machinery. The service performance of these two vessels will be watched and compared with great interest. The lighter installation of the *Morar* permits an increase in deadweight of about 200 tons.

G.T.S. "Goodwood"

The *Goodwood* has been converted from steam reciprocating machinery. The new normal power requirement is 1,700 shp and this is provided by an Alsthom turbine supplied with exhaust gas from two GS.34 gasifiers, built by the Smith's Dock Co., Ltd., South Bank, under licence from Alan Muntz & Co., Ltd. The turbine is a single-casing machine with six ahead stages and one astern stage carried on a one-piece gashed rotor. The inlets to both ahead and astern turbines are divided so that one gasifier supplies each half section. By this means, each gasifier can develop full, designed, gas-delivery pressure when working alone, as well as when both are working together.

Many owners have vessels, the hulls of which are in good condition but whose machinery is obsolete so that the whole ship is uneconomic. The conversion of the *Goodwood* seeks to demonstrate that such tonnage can be made fully competitive with present-day new buildings. A sister ship—the *Birdwood*—is being converted from similar steam reciprocating machinery to medium-speed geared Diesel propulsion.

Service Results of the G.T.S. "William Patterson" and "John Sergeant"

Results were quoted in a paper entitled "Operating Experience with Gas-turbine Ships of the U.S. Maritime Administration," by Mr. C. C. Tangerine and Mr. D. H. Specht and read at the Gas Turbine

Conference in March, 1959 of the American Society of Marine Engineers.

It will be remembered that the *William Patterson* has six free-piston gasifiers feeding two turbines geared to a single shaft and at the last moment the clearances of the ahead turbine were modified to such an extent that the fuel consumption was adversely affected. At the trials, 6,090 shp, 4,009 shp and 2,005 shp were developed using six, five and four gasifiers, respectively, fuel consumption being 0.465 lb. per shp-hr. at highest power. The average speed during the second voyage was 14.5 knots, with displacement of 13,350 tons and an average power of 4,100 shp, the fuel consumption being 0.537 lb per shp-hr. Certain modifications were made to the turbines after the third voyage to obtain better matching with the gasifiers and at the same time internal clearances were reduced to improve turbine efficiency. With a displacement of 13,650 tons on the fourth voyage the average speed was 14.6 knots at average power of 4,200 shp and fuel consumption was improved to 0.519 lb per shp-hr.

The *John Sergeant* is propelled by a regenerative open-cycle gas turbine. During the two years following its completion, in September, 1956, the vessel covered over 94,000 nautical miles with a total of 6,567 operating hours for the propulsion plant. The normal power fuel rate averages 0.522 lb. per shp-hr. which also represents the all-purpose fuel rate since sufficient steam for all auxiliary purposes is generated in the waste-heat boiler at powers down to 3,500 shp without additional oil firing. It is stated that the rotors, blading, shaft seals, and nozzles have needed no adjustment or repairs. Simple routine inspections are made about every three months during normal port time.

G.T.S. "Auris"

The sea trials of the *Auris* were successfully completed toward the end of August. The gas turbine set installed is one of a set of two which it had been originally proposed to install in a twin-screw tanker of 18,000 tons. Plans were changed, however, and only one set was built and has been installed in the *Auris*. Two-stage compression is used with intermediate intercooling. The h-p turbine drives the h-p compressor and the l-p compressor is driven by the l-p turbine which also supplies the power output to the propeller shaft, net. Bhp at l-p turbine output coupling being 5,500 bhp.

Double-helical, double-reduction gearing of ratio 32:1 is provided; the forward end of the primary pinion is connected to the driven member of a hydraulic torque converter and the after end is connected to the driven end of an ordinary hydraulic coupling. The l-p turbine output coupling is flexibly connected to a quill shaft, running within and through the primary pinion, and on it are mounted the appropriate driving members of the hydraulic torque converter and the hydraulic coupling. Thus with uni-directional rotation of the turbine, the propeller can be driven ahead or astern by filling the appropriate hydraulic unit. A friction clutch can be engaged for normal ahead running at sea, so that hydraulic coupling losses can be eliminated. On trials, the reversing mechanism behaved satisfactorily and afforded rapid maneuvering, nevertheless, it has been decided to modify the torque converter in an attempt to improve its efficiency. Table II gives some particulars of the installation. Auxiliary steam is raised in a waste-heat boiler of forced circulated La Mont type; by accepting a pressure of 50 psi about 5,000 lb per hour can be generated and superheated to a temperature of 350° F. The coupling of the l-p compressor to the l-p turbine (which is also the power turbine) has a valuable stabilizing effect, and as it eliminates the possibility of the turbine being completely unloaded say, during maneuvering, the provision of a gas by-pass valve is unnecessary.

TABLE II

Net turbine output (at l-p coupling)	5,500 bhp
Ambient air temperature	23°C
Ambient air pressure	(7.5°F)
Pressure ratio	6 : 1
Intercooler thermal ratio	84 per cent
Turbine inlet temperature	650°C (1,202°F)
H-P turbine speed	5,800 rpm
L-P turbine speed	3,840 rpm
Propeller speed	120 rpm
Designed fuel rate	0.52 lb/bhp hour
L.C.V. of fuel	17,500 btu/lb.

Residual fuel of 1,200 seconds Redwood No. 1 at 100° F has been satisfactorily used for free running and for maneuvering, the four identical pressure jet burners being of the return flow type having a spring loaded tip shut-off valve, which will permit circulation of heated residual fuel up to the tip and back to the service tank when starting from cold or during a prolonged stop while maneuvering. The designed fuel consumption is 0.52 lb per shp-hr.

The *Auris* installation has demonstrated that the fuel economy of the conventional gas-turbine set, designed for long life and capable of burning residual fuels is unlikely to be better than that of a comparable steam-turbine set, so long as gas temperatures are not allowed to exceed 1,250° F and this is considerably poorer than that of a corresponding Diesel-engine installation. Furthermore, it is clear that the expected lower maintenance costs will not be sufficient to off-set the higher capital costs of a gas-turbine unit of this design. Any development of blading materials, blade cooling systems, or fuel additives which permit long-life turbines to use temperatures in excess of 1,200 to 1,250° F, and still keep clear of deposition and corrosion trouble, can, of course, alter the position markedly, provided the first cost of the designs

made possible is not increased due to the special materials required.

MISCELLANEOUS

Cathodic Protection—Hulls

In July, 1954, thirty zinc anodes, to a specification requiring less than 0.0014 per cent iron, were welded to the bottom of a United States Navy tug for cathodic protection tests. Hull potential readings were taken over a period of 15 months, at the end of which time it was dry-docked and the underwater area was found to be in excellent condition with only about 20 per cent of the zinc consumed. The vessel was, therefore, returned to service without repainting and with the anodes intact. After a further 26 months' service, during which readings of hull potential continued to be taken, the vessel was again dry-docked. About 75 per cent of the zinc had been consumed over the whole 41 months. The paint was in good general condition, and no corrosion was found on the hull bottom, rudder or propeller.

Mr. H. S. Preiser and Mr. B. H. Tytell have reported fully on this second test period in a paper to the *Journal of the American Society of Naval Engineers,* May, 1959, having previously reported the results of the first 15 months also in the Journal. In the present paper, they make some comparison in efficiency and cost with anodes of aluminum and magnesium. They conclude that zinc anodes of the specification used are suitable for the protection of active ships, and possibly for ships laid up in seawater berths; current output is not greatly affected by the surface corrosion which appears on the anodes; the system is self regulating and efficiently provides current on demand, induced turbulence is very small. Zinc of this specification has an ampere-hour capacity per pound of 350 at an efficiency of 95 per cent and it is stated to be one of the most economical galvanic anode materials for active ships requiring moderate amounts of protective current.

In 1948, six magnesium anodes were installed on the *Edco,* a tug in the service of the Dow Chemical Company's Texas Division on the Gulf Coast near Freeport. Since then, with periodic anode replacements, it has not been necessary to repaint the hull below the waterline. The Dow Company have since developed a plastic-coated magnesium anode which is used to protect the *Delta VI,* an oil-drilling tender on Lake Maracaibo. The coating can be cut away selectively with a knife or other instrument to expose the desired amount of anode surface. Only the face most remote from the hull is exposed, the plastic covering on the bottom and sides being left intact, thereby improving current distribution and virtually eliminating calcareous deposits which used to form on the hull around bare anodes indicating excessive local current density.

The Dutch passenger liner *Willem Ruys* went into service early in 1948, and during the first three years was dry-docked annually. With the development of severe rivet and weld corrosion, frequency of dry-docking was increased to twice per annum. This brought the corrosion under control, but the underwater surface became very rough. In 1954-55, it was decided to sandblast the underwater hull, paint it with four coats of International Silver Primocon and one coat of International Supertropical Anti-fouling, and to employ a trailing wire system of cathodic protection which has been developed by the owners, the Royal Rotterdam Lloyd. Subsequent annual dockings showed that the hull remained in excellent condition. Before a recent inspection the vessel had been on the East Indies route for 16 months without docking. No corrosion had occurred and there was very little fouling. During 1957-58-59, the ship's resistance has been only 11 per cent above that estimated from tank measurements without allowance.

This type of cathodic protection is suitable for high-speed liners, since the thin aluminum wire causes no measurable resistance. The equipment is manufactured under license by the Sunderland Forge and Engineering Co., Ltd., Pallion, Sunderland, and is being used by a number of shipowners.

Cathodic Tank Protection

Zinc-rich coatings offer many advantages over other corrosion control systems now in use in tankers. They provide excellent protection against corrosion and are equally effective in tanks carrying clean or dirty oils. The tanks are easier to clean and gas-free, and the cleaning can be done with unheated water. Scale removal is eliminated.

One such coating material, known as Dimetcote, has been under test in two ships of the Esso fleet since 1956. It consists of liquid sodium silicate and a fine zinc powder, and it is applied to the tank surfaces by spray gun. After the coating has dried, a curing solution is sprayed on, allowed to dry for 24 hours and finally the tank is washed down with cold water. As a preliminary treatment, the surfaces must be cleaned to bare metal by sandblasting. Because of the extremely satisfactory results of these experiments this coating has been adopted for the Esso Company's 27,300-ton deadweight tankers in clean service.

The first of 17 oil tankers on order for the P. & O. Group has been delivered to the Federal Steam Navigation Co., Ltd. This vessel—the *Lincoln*—is on charter to the British Petroleum Co., Ltd. Twenty of her 27 cargo oil tanks have been equipped with the Guardion multi-fin cathodic protection system, installed by Messrs. F. A. Hughes & Co., Ltd., London; the remainder have been coated with an epoxy-resin paint.

Tank Heating by Conical Coils

Experimental tanks in four ships of the Shell fleet have been fitted with conical heating coils, but it is believed that the first tanker to go into opera-

tional service with this device is the R.F.A. tanker *Broomdale;* the coils were supplied and fitted by Messrs. Charlton, Weddle & Co., Ltd., Newcastle-on-Tyne. Each coil consists of 292 feet of 1½-inch, 14 gauge aluminum brass tube (built up of four 73-foot lengths to reduce number of joints), 20 feet high, 3 feet, 6 inches outside diameter at base tapering to 1 foot, 2 inches outside diameter at the apex. The coils are pitched spirally at 6 inch centers and each completed coil has 125 square feet of heating surface. There is a supporting tripod framework of mild-steel angle bar, 1½ inch by 1½ inch by 1¼ inch, to which the tubing is attached with 2-bolt type aluminum brass clips. In order to protect aginst fatigue cracking, the coils are stress relieved after being stretched on to the tripod supports—lead lined steel clips or plastic clips would not stand up to stress relieving temperatures, hence the need for aluminum pipe clips. The base of a coil is secured to channel sections between main longitudinals and the apex is staved to a bulkhead.

Fabrication costs per foot of tube length are in favor of traditional bottom grids, but the conical coil is overall the cheaper as the length of tube is decreased by 50 per cent (due to increased rates of heat transfer), and fitting costs are lower. There is also a saving in weight of just over 10 per cent in favor of conical coils.

Tank Cleaning

In the Groom tank-cleaning process, residual oil and sludge is removed by washing down the tank surface with a warm detergent solution which circulates in a closed cycle through the tanks being treated and the cleaning plant. In this latter the mixture is heated and then allowed to separate into its three components of oil, sediment and detergent solution. The plant is usually provided with two rotary projectors.

The Intveld tank washing machine is used by suspending it in the tank to be cleaned, rotating about a vertical axis while its nozzles are caused to oscillate slowly about horizontal axes. Two nozzles rigidly conected together at right angles form a unit, so that one sweeps the upper and the other the lower portion of the tank. As the unit is lowered the path of each hot-water jet generates a spiral, successive turns being close enough to ensure that no part of the tank is left untouched. The transverse motion of the jets is essentially horizontal, which is advantageous since residues tend to collect on the horizontal ledges formed by structural members. The flow through each nozzle can be adjusted and the speed of rotation and working pressure can be varied to suit the need of individual tanks with consequent saving of time.

In "Systematic Checking of the Contents of CO_2 Cylinders," by Mr. H. Lammenet (*Hansa,* December, 1958), it is stated that regulations for carbon dioxide fire-extinguishing installations on ships require that the storage cylinders be examined at regular intervals for leakages. This is usually done by weighing the cylinders; a tedious and sometimes difficult job. A new type of equipment enabling the liquid level to be ascertained has been developed and the cylinder contents can be calculated from a knowledge of the level.

The instrument is essentially a U-shaped fork and has been developed by Walther & Cie A. G. Köln-Dellbrück. One prong carries a source of radiation and the other a Geiger counter which requires only a 1.5-volt battery. A headphone is connected to the Geiger counter so that an audible signal is given when radiation impinges on the counter. The U-fork, held in such a manner that the cylinder is interposed between the source and the counter, is moved slowly up the cylinder and as the liquid level is reached, the frequency of received signals rises immediately. A half-life of more than 20 years guarantees a practically uniform radiation intensity from the isotope.

Seaway Equipment

Some delays to shipping in the St. Lawrence Seaway have been due to vessels not being properly equipped to navigate the locks. The Seaway Authority has, therefore, added Circular No. 3 to its Regulations to give details of the equipment required or recommended. Medium-frequency radiotelephone is obligatory and it is recommended that VHF equipment should also be fitted. Mooring gear, fenders, masts and draft marks are subject to mandatory regulations. Recommendations are made concerning stern anchors, gear for putting men ashore to assist in securing the ship, a visible and audible "wrong-way" propeller direction alarm system, and septic tanks.

It is understood that regulations will probably be made affecting navigation lights, rudder angle and rpm indicators.

ROBERT TAGGART

RECENT MARINE PROPULSION DEVELOPMENTS

THE AUTHOR

is President of Robert Taggart Incorporated, a new firm organized to do contract research and development work in naval architecture, hydrodynamics, acoustics, and propulsion. He received his Bachelor of Science degree in Naval Architecture and Marine Engineering from Webb Institute of Naval Architecture in 1942. He has served with the Consolidated Steel Corporation, U. S. Maritime Commission, U. S. Army Transportation Corps, the Naval Research Laboratory, the Bureau of Ships of the Navy Department, and Reed Research, Inc.

INTRODUCTION

PRECEDING ARTICLES of this series have traced the history of marine propulsion back to the earliest mechanisms invented by man to propel waterborne vehicles. Although many ingenious devices have been invented, it is only within the last one hundred and fifty years, since the advent of practical mechanical power sources, that real progress has been made.

Despite the great accomplishments of this last century and a half, and despite the myriad schemes which have been proposed and tried, new inventions and further developments continue. New types of ship machinery are being tried; the screw propeller is being modified to deliver more and more propulsive power; completely different forms of propelling devices are being designed.

Some of these developments have been made possible by scientific advances in allied technologies; others are merely the application of known physical concepts to the field of ship propulsion. Any historical account of technological progress can do no more than account for what has occurred up to the moment of writing, with perhaps a qualified guess as to what may lie ahead. In a dynamic field such as ship propulsion any account of progress is destined to be out of date before it goes to print.

SHIP PROPULSION MACHINERY DEVELOPMENTS

The most notable and exciting development in marine propulsion machinery in the last decade has been nuclear propulsion. The first atomic reactor for ship propulsion stemmed from a Manhattan District project designated "Daniels Power Pile," whose goal was to develop a small industrial reactor. Navy representatives and others working on this project were intrigued with the possibilities of such an indefatigable heat source and when, in 1946, Dr. A. M. Weinberg of Oak Ridge proposed a high-pressure, water-cooled reactor as a power unit, the idea was received most enthusiastically.

In December 1947 the Navy requested the Atomic

Energy Commission to design and construct a reactor for a submarine. In 1948 the Submarine Thermal Reactor (STR) project was formally established. This project was assigned to the Westinghouse Electric Corporation and active development started in 1949. Two reactors were built, STR Mark I and STR Mark II. The Mark I plant first became operative at the Reactor Test Station in Arco, Idaho, on March 30, 1953 and extensive performance tests on the entire steam plant were run.

During this period, the Electric Boat Division of General Dynamics Corporation was studying the many problems of installing a radioactive steam power plant in a submarine. Although the reactor is, in essence, only a source of heat for a boiler to be used in driving a conventional steam turbine propulsion plant, an extensive array of problems had to be overcome. A diagram of a submarine power plant is shown in Figure 1.

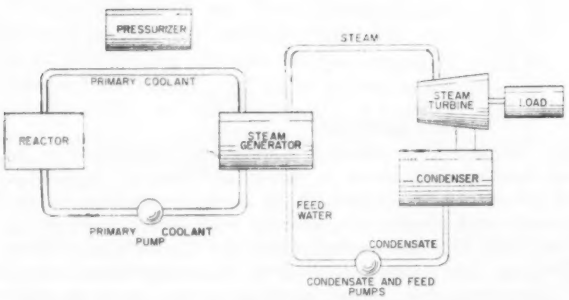


Figure 1. Diagram of the *Nautilus* Propulsion Machinery Plant.

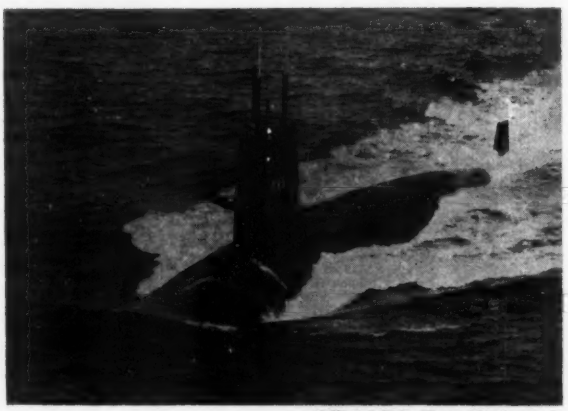
The keel of *Nautilus* was laid in Groton, Connecticut, on 14 June 1952, and was launched on 21 January 1954. As *Nautilus* slid down the ways a new era of submarine warfare was launched. Her amazing performance and underwater endurance have enforced a completely new set of concepts in strategy and tactics of battle beneath the seas.

The success of *Nautilus* curtailed the development of many other types of closed-cycle propulsion plants, which were then in experimental stages. Work on hydrogen peroxide plants, oxygen-fed steam plants, and closed-cycle diesel engines practically came to a halt when it was found that nuclear power was a successful answer to the problem of keeping a submarine at depth for extended periods. The obvious next step was to combine this basic propulsion machinery with the most efficient hull form and propulsion device to achieve the optimum in underwater speed, endurance, and fighting capability.

Submarines had traditionally been surface craft, with the ability to submerge for concealment during the attack and escape phases of their operations. Submarine hulls were designed with seaworthy surface operation as a primary criterion and underwater operation as a secondary criterion. Since the two criteria were not particularly compatible, underwater performance had suffered. Now it was possible to remain submerged for extended periods, thus permitting the designer to alter the hull form to that which was most efficient for continuous submerged operation.

In a development paralleling that of the *Nautilus*, the Navy had already confirmed model test results of the optimum in underwater hull forms. The submarine *Albacore* had been built and tested extensively for the specific purpose of demonstrating what could be accomplished in the design of a true submersible when the surface capability restriction was removed. Speeds far in excess of those of existing submarines were attained and underwater maneuverability approached that of military aircraft.

The marriage of the nuclear propulsion plant and the Albacore hull form was first consummated in the submarine *Skipjack*, Figure 2. This ship was the first in what is expected to be a series of submarines built with similar hull forms and propulsion systems. These submarines, with their tremendous military capabilities, are changing the course of naval warfare from almost total surface operation to advantageous use of the ocean depths.



Official U.S. Navy Photograph

Figure 2. The Nuclear-Powered Submarine *Skipjack*.

Nuclear power is also making headway in the surface navies of the world. In the United States nuclear powered cruisers and aircraft carriers are being constructed. The Russians have a nuclear powered ice-breaker, and other countries are considering the use of nuclear power in military surface ships. Although now inherently more expensive than the conventional marine propulsion plant, it promises to extend the range of naval surface ships. By placing less reliance on refueling ships and thus improving flexibility, it becomes economically feasible to use nuclear propulsion in naval ships.

At the present time this economical feasibility cannot be extended to merchant shipping. Not only the initial investment and the high cost of the fuel must be considered, but also the added personnel required to run such a power plant must be added to the operational expenses.

Nevertheless, the United States is gambling on a future reduction in the first cost and operational costs of nuclear power for merchant ships. The *NS Savannah,* Figure 3, launched at the New York Shipbuilding Corporation yard in Camden, New Jersey, on 21 July 1959 is the world's first nuclear-powered merchant ship. From her first few years of operation, it will be possible to determine many of the factors which must enter into the cost equation when using this means of propulsion for carrying cargo and passengers across the seas.

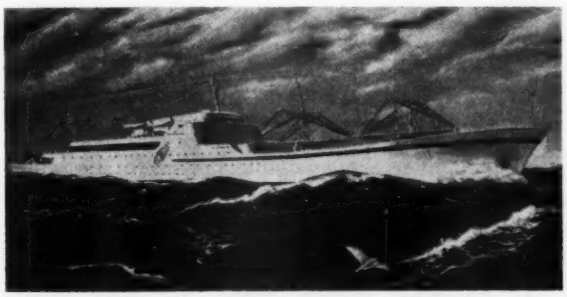


Figure 3. The Nuclear-Powered Merchant Ship *N. S. Savannah*.

Another type of propulsion machinery plant which has had an influence on propeller design is the gas turbine. Although the gas turbine was suggested many years ago by Leonardo da Vinci, it has only been in recent years that metallurgical developments have made a practical turbine possible.

The first marine gas turbine was installed in 1947 in the British motor gunboat *MGB 2009*. This was a 2500 horsepower, medium-life, simple-cycle engine which drove the center shaft of the triple screw boat. The *MGB 2009* was 116 feet in length and displaced 100 tons. The gas turbine installation is shown in Figure 4. The Admiralty claimed as advantages of the gas turbine: less specific weight and volume, less time from cold start to full power, less complication and vulnerability, use of low cost fuel, and low maintenance costs.

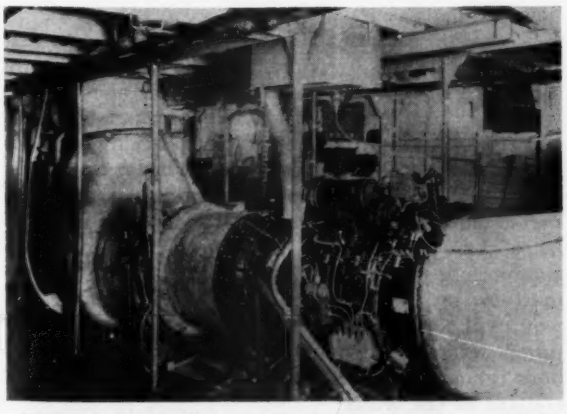


Figure 4. Engine Room of the Gas Turbine Powered British Gunboat MGB 2009.

In 1950, two 120 horsepower, 30,000-RPM gas turbines were installed to drive the outboard shafts of the triple-screw, 60-foot launch *Torquil*. These turbines had been developed by the Rover Company in England for use in a sports car. Less than a month after the *Torquil* first put to sea, trials were started on a Boeing gas turbine installed in a U. S. Navy plane personnel boat. This was the first boat to be powered solely by a gas turbine. The turbine was a 160-horsepower machine turning at 22,650 revolutions per minute. Reversing was accomplished through a Snow and Nabstedt marine reverse gear. Subsequently, gas turbines were installed in the British Naval Harbor Launch No. 3964, in a U. S. Naval landing craft (LCVP), and in the Anglo-Saxon Petroleum Company tanker *Auris*.

The first United States gas turbine merchant ship was the *John Sargent,* which is a converted Liberty Ship of 6000 horsepower. The system heat balance for this gas turbine plant is shown in Figure 5. Since reversing gears in large ships are impractical, the *John Sargent* is fitted with a controllable pitch propeller for both maneuvering and reversing. This ship went into service in the summer of 1956 and, since then, the operation of both the gas turbine and the controllable pitch propeller have been entirely satisfactory.

The *John Sargent* was followed in the U. S. Maritime Administration Liberty Ship conversion program by the *William Patterson*. This ship, also driven by a gas turbine, utilized a free piston compressor to provide air to the turbine. Another interesting feature of this power plant is the incorpo-

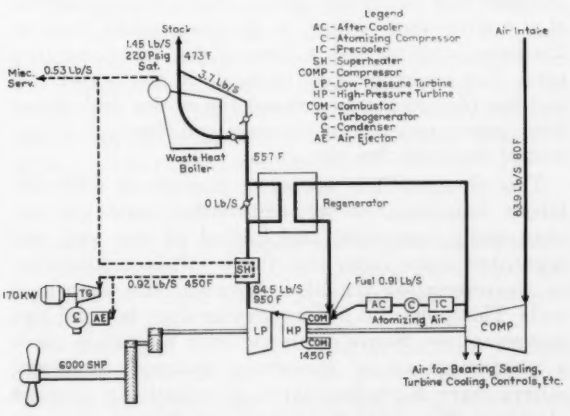


Figure 5. Gas Turbine Installation in the *John Sargent*.

ration of an astern gas turbine which permits use of the conventional fixed-pitch screw propeller.

Gas turbines have proven to be efficient and reliable power plants for marine propulsion in both large and small vessels. In addition to burning a cheap fuel and driving a screw propeller, the gas turbine has other marine propulsion possibilities. Studies are now in process to determine the feasibility of combining the nuclear reactor directly with the gas turbine, to form a compact and efficient marine power plant.

In the field of submarine propulsion systems, two additional power plant developments are of interest. The midget, four-man submarine *X-1*, built for the U. S. Navy by Fairchild, employed hydrogen peroxide as an oxidant for running its diesel engine when submerged. This system has been developed to the point where it has worked quite successfully except for the danger in handling high concentrations of hydrogen peroxide.

Another submarine power source under development is the primary battery, or fuel cell. Laboratory tests have demonstrated that it is feasible to provide a constant flow of chemicals into a battery which generates electricity as the chemicals combine. Difficulty in handling the fuels and in controlling exactly the relative quantities involved presents many problems, but none that will not be overcome eventually. This development is reminiscent of Jules Verne's *Nautilus*, in which Captain Nemo used chloride of sodium in sea water to generate his electricity.

An additional power source now under development which is of interest is thermo-electricity. Basically this term is applied to the direct conversion of heat into electric power or, conversely, the pumping of heat by an electric power input. Thus the principle can be applied either for power generation or for refrigeration; the former use is of basic interest in marine propulsion.

Thermo-electricity is based on the Seebeck effect, named for its discoverer, a 19th century physicist. This effect is that when a heat source is supplied to one end of a conductor and a heat sink is provided at the other end, a flow of electrons takes place in the same way as does a flow of gas contained in a tube. The electron "gas" expands in the hotter end and the electrons flow toward the cooler end where they concentrate, thus causing a difference in potential between the two ends.

This electron flow varies in magnitude with different materials. If two dissimilar materials are electrically connected and heated at one end, and separated at the other end, there will be a difference in the electrical potential between the separated ends. This potential difference can then be used as a power source. Some semiconductor materials carry a predominance of positively charged electrons; others carry a predominance of negatively charged electrons. By employing a positive charge carrier in one leg of the V configuration and a negative charge carrier in the other leg, the potential difference between the two can be augmented.

Although this method of power development is in its infancy, it holds great promise for the future. Already small mechanisms have been powered thermo-electrically and materials research in semiconductors is proceeding rapidly.

The machinery developments and potential power sources which have been described here are bound to have a pronounced effect on ship propulsion devices. Just as jet engines and rocket power are revolutionizing aircraft design, so must marine design be influenced by the availability of greater power in smaller packages. It will be a challenge to the naval engineer to provide the means for converting this power into useful thrust for the propulsion of larger and larger ships at higher and higher speeds.

THE CAVITATION BARRIER

More powerful and compact machinery will permit the ships of the future to move at increasing speeds through the water. The propulsion device used to deliver the available power to the water must also move at a greater rate of speed. As the speed of the ship and of the propulsion device increase, a collision with the cavitation barrier is inevitable.

As described earlier, when any body moves through the water at progressively increasing speeds a speed is reached where the water cannot close in behind the body fast enough, and a cavity is formed. This cavity is a low pressure region which essentially causes the water to boil, thus filling the cavity with small bubbles of water vapor. Dissolved air or foreign matter in the water provides a weakness in the water structure; the vapor bubbles tend to form about small nuclei of air or foreign particles. When these bubbles move into a higher pressure region, they collapse with large forces which make noise, erode propeller blades and appendages, and which cause severe losses in efficiency.

Cavitation can be delayed by balancing out pressure irregularities, by increasing the pressure in the cavitating area, or by reducing the air and foreign matter content of the liquid. Screw propeller design has progressed to the point where the pressure irregularities are minimized and similarly struts and other hull appendages are carefully designed for non-cavitating flow insofar as possible. Pressures have been increased in cavitating areas either by submerging the entire vessel, as in the case of submarines, or by locally increasing the pressure in way of the propulsion device, as in the case of the pump jet and shrouded propellers. Little can be done about reducing the air and foreign matter content of sea water.

The pump jet design is a practical method for

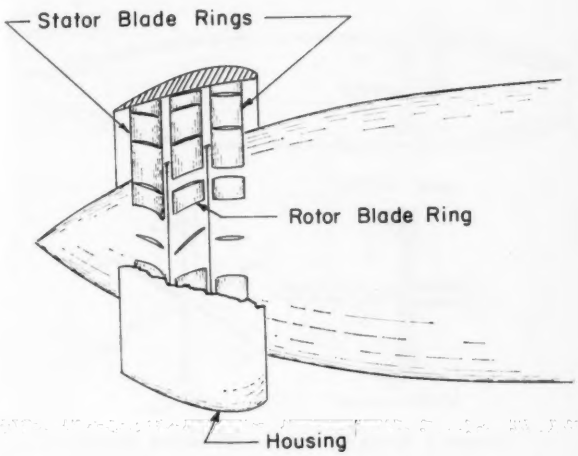


Figure 6. One Type of Pump Jet Installed on the After End of a Torpedo.

delaying the onset of cavitation as ship and underwater missile speeds are increased. It consists of a series of rings of small blades mounted within a faired housing as shown in Figure 6. The fartherest forward blades are mounted in a stator ring and serve to direct the flow efficiently into the following ring of rotating blades. The after blade ring is also fixed and is employed to straighten out the flow, leaving the rotating blades, and to recover additional thrust.

The housing which encloses the blade rings is so designed that the cross-section area of the flow between the hub and housing increases in way of the rotor blades. The velocity in this region is therefore decreased and the pressure correspondingly increased. The increased pressure serves to prevent cavitation or, at least, permit non-cavitating operation at higher speeds than could be achieved with an unshrouded propeller.

It becomes obvious, however, that at truly high surface ship speeds of fifty knots and above, the suppression of cavitation becomes impossible. Thus there is a need for a propulsion device which can operate efficiently in this speed range.

The answer has been the supercavitating propeller. This is a propeller whose blades are so designed that they will operate with the suction side of the blade sections being completely enclosed within a vapor cavity which extends from the leading edge of the blade to a point beyond the trailing edge.

The majority of the work done in the design of supercavitating propellers has been a joint effort of the Office of Naval Research, the Bureau of Ships, and the David Taylor Model Basin. An example of the supercavitating propeller blade section as compared with that of a conventional screw propeller is shown in Figure 7.

When cavitation is fully developed around the

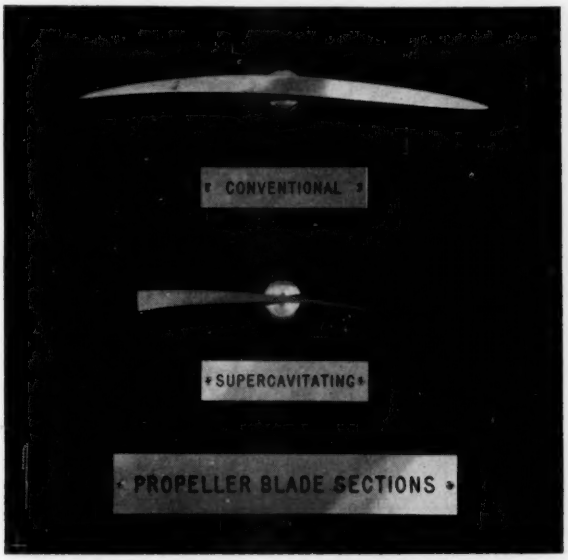


Figure 7. Blade Section of a Supercavitating Propeller Compared with that of a Conventional Propeller.

blade of a supercavitating propeller, it is possible to attain efficiencies which are comparable with that of the conventional screw propeller operating under non-cavitating conditions. A disadvantage of this new design is, however, that at lower speeds of advance the efficiency drops off sharply. Thus the supercavitating propeller is truly effective only when operating at high speeds. For naval ships, which operate at top speed only a small fraction of their lifetime, this is an inherent limitation of the supercavitating propeller.

This disadvantage is being corrected by artificially increasing the cavity pressure under low speed operating conditions. The method employed is to provide an air passage from the back of the blade through which air can either be sucked or injected. These are known as ventilated, or forced-ventilated, propellers.

The supercavitating propeller is not the complete answer to breaking the cavitation barrier. Its range of application is limited and it does little to correct the problem of cavitation noise. Nevertheless, it development is a large step forward in providing a means for ships to utilize modern power plants to attain greater operating speeds.

REACTION DEVICES

Several types of propulsive devices which might be categorized as reaction devices have been developed in recent years. A description of three of these types may be of interest.

In 1946 H. J. de N. McCollum of Chicago, Illinois, patented the outboard motor shown in Figure 8. This simple mechanism burns gas in a combustion chamber in a series of pulses controlled by a flapper

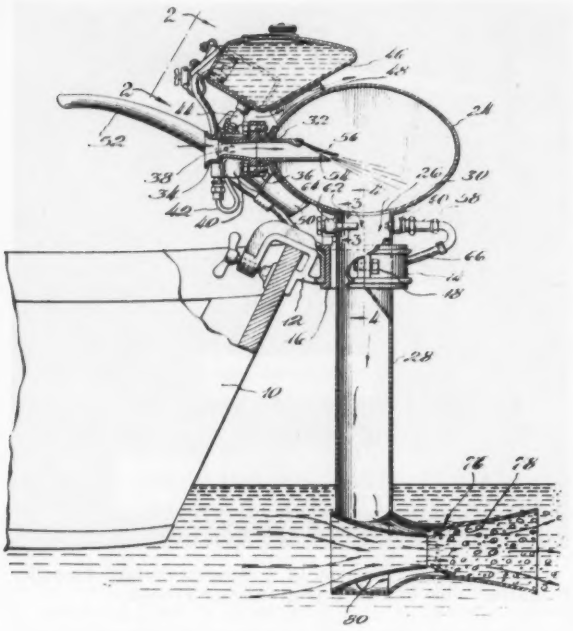


Figure 8. McCollum's Jet Outboard.

valve on the air intake. The gas exhausts through an annular nozzle which surrounds a water intake nozzle below the water surface. After the kinetic energy of the gas is imparted to the water in the throat of the nozzle, the combined mixture is discharged at reduced pressure through an expanding nozzle.

Fritz Zwicky of Pasadena, California, patented a water-reactive chemical propulsion device in 1949. A diagram of his proposed configuration is shown in Figure 9. Three liquids were supplied to the reactor: water, a water-reactive chemical, and a surface tension depressor. The water and the water-reactive chemical, such as lithium borohydride, were fed separately through concentric pipes to the reaction nozzles, 21, where they were combined. The surface tension depressor was separately fed to the Christmas tree-like series of emitters in the center of the main nozzle. The explosive reaction between the chemical and the water forced surrounding fluid through the main nozzle at high velocity. The surface tension depressor served to reduce the water film surrounding the individual bubbles, which were the product of the chemical reaction, thus permitting more efficient transfer of energy between the bubbles and the fluid.

A recent development of the Aero-jet General Corporation in Azusa, California, is the Hydrocket. This device in some ways resembles a hydraulic jet except that water is discharged at very high speeds above the water surface. The pump, or Hydrocket, is an adaptation of a centrifugal pump, and is mounted at the stern of the craft to be propelled

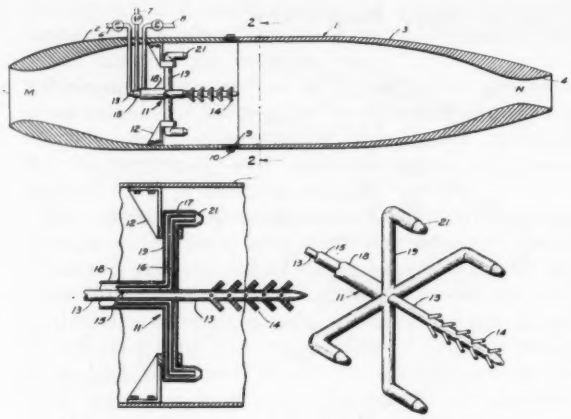


Figure 9. Zwicky's Reaction Propelled Device.

with its axis horizontal in a fore and aft direction.

Water is taken from a scoop beneath the craft into the center of the pump. The pump rotor is a disc fitted with radial holes leading toward the outer periphery, but turning through 90° to discharge through the after face of the disc. The water is thus accelerated outward by centrifugal force and then turned to discharge in a spray aft. The momentum reaction of water in being turned aft provides a resultant forward thrust to the craft. This system is purported to permit very high-speed operation.

UNDERWATER MISSILES

A brief history of torpedo development was given in earlier sections. In the years since World War II probably the greatest advances have been made in the field of torpedo, or underwater missile, propulsion. Many of the patents which have been described showed methods of using high pressure gases, or products of combustion, directly to force water through a nozzle. High speed underwater missiles are the most natural vehicles to benefit by this form of propulsion.

As submarine speeds and operating depths have increased, it has become essential that the weapons intended for use against them also operate at higher speeds than heretofore. The steam and electric torpedoes of World War II are no longer effective weapons. Although the old lead-acid batteries in the electric torpedo have been replaced with the lighter and smaller silver cell batteries or magnesium-seawater-silver-chloride primary batteries, a thermal power plant is still required for higher speed and longer range missiles. The upper diagrams A and B in Figure 10 show the older steam and electric torpedoes which have been previously described. Water reactive fuels such as lithium or magnesium may be combined, as in C, in a combustion chamber and the gaseous product used to drive a propeller through a steam or gas turbine. Or the

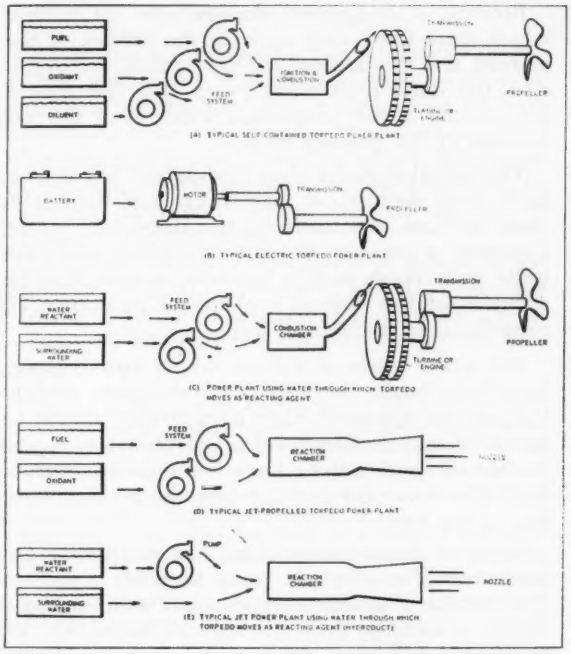


Figure 10. Methods of Powering Underwater Missiles.

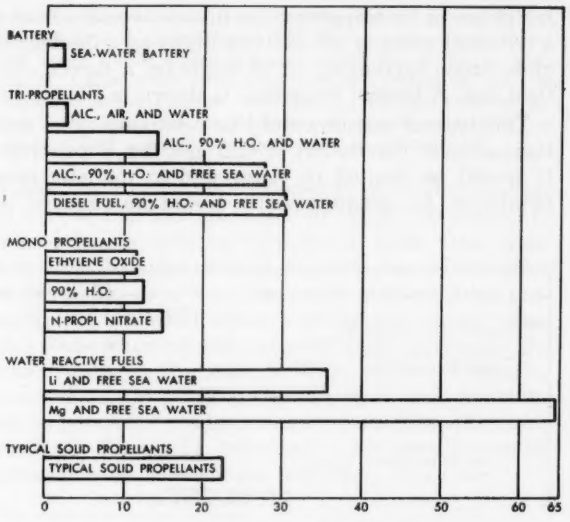


Figure 11. Comparison of Propellant Performance.

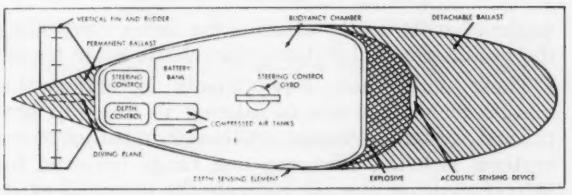


Figure 12. An Underwater Missile Driven by Gravity and Buoyancy.

airborne rocket technique may be employed as in D, where a fuel and an oxidant are combined in a combustion chamber which exhausts directly to the sea, driving the missile forward by reaction. Finally, a water reactant may be combined directly with the surrounding water in a combustion chamber as in E and the missile driven by the resulting reaction. Solid propellants may also be burned directly at the after end of the missile to propel it forward by reaction. The comparative performances, on a theoretical basis, of these various methods of propulsion is shown in Figure 11.

Another possible solution to the propulsion problems of high speed underwater missiles is the elimination of propulsion systems entirely. Two forces always are available for underwater missile propulsion—gravity and buoyancy.

One concept of a missile employing these forces is shown in Figure 12. A heavy, detachable ballast weight forms the nose cone. When this cone is in place the missile is excessively heavy in the water. Upon release from a surface ship, aircraft, or submarine, it would drop straight for the bottom reaching a terminal velocity which would be determined by its waterborne weight and its resistance. Control of the diving planes could convert this vertical motion into a glide path at an angle of as little as 30 degrees with the horizontal. At the greatest depth available the nose cone could be released, at which point the missile would become buoyant. It would then rise, reaching a terminal velocity determined by the buoyancy and the resistance of the new and smaller form. Again diving planes could be controlled to force the missile into a glide path leading it away from the launching vessel and toward the target.

A gyroscope is provided for directional control and a pressure sensing diaphragm is included to determine the release point of the weighted nose cone. In the nose of the buoyant body an acoustic sensing device is included, which would be used to control steering and diving planes, to direct the missile to the target.

The potential of such a missile can best be shown by estimating the performance of a hypothetical design. Using the general configuration of the missile shown in Figure 12 with a length of 18 feet and a diameter of 4 feet, the buoyancy would be on the order of 9000 pounds. If the nose ballast were a solid steel casting, its weight would be about 15,000 pounds. Assuming the weight of the structure and warhead to be 2000 pounds, the excess weight would be 8000 pounds. In the dropping phase this missile would reach a terminal velocity on the order of 70 knots in a vertical direction. At a 30-degree glide angle this speed would drop to about 30 knots.

After release of the nose ballast the reserve buoyancy would be about 7000 pounds. During the ris-

ing phase of its trajectory the missile would achieve a terminal velocity of about 25 knots on a 30-degree glide angle increasing to 60 knots on a direct vertical rise. A typical trajectory is shown in Figure 13.

This type of missile would be relatively quiet and inexpensive. Cavitation would not be a problem. It would be limited in range and in maneuvering flexibility. Its greatest value would be realized in

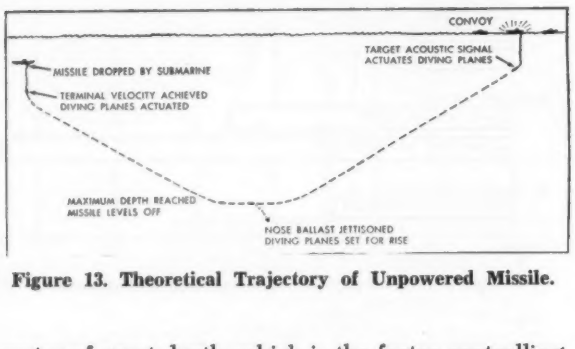

CONVOY
TARGET ACOUSTIC SIGNAL ACTUATES DIVING PLANES
MISSILE DROPPED BY SUBMARINE
TERMINAL VELOCITY ACHIEVED DIVING PLANES ACTUATED
MAXIMUM DEPTH REACHED MISSILE LEVELS OFF
NOSE BALLAST JETTISONED DIVING PLANES SET FOR RISE

Figure 13. Theoretical Trajectory of Unpowered Missile.

water of great depth, which is the factor controlling the total horizontal distance the missile could travel.

These and other developments in underwater missile technology are of interest to the ship propulsion system designer. Although most of these systems lack the efficiency and range required for ship propulsion, they do indicate the potential existing in forces not normally employed for moving surface ships through the water.

FISH PROPULSION

Throughout the technical and popular literature references to methods of propelling ships in a manner simulating the action of a fish have appeared for many years. Methods ranging from flapping a rigid tail to Boerner's *Gill Boat* to the undulating fin have been suggested. While some of these methods tend to duplicate the motions of aquatic creatures, others are based on completely erroneous concepts of fish propulsion.

In recent years attention has been devoted to learning how aquatic creatures swim and maneuver rather than to duplication of their actions experimentally. When discussing fish propulsion, it is first necessary to define what form of fish propulsion is being considered. Aquatic creatures move themselves through the water in many different ways. Some creatures row themselves through the water by fore-and-aft motion of flippers, fins, or feet using a feathering action. Others utilize a sculling motion involving a combination of transverse and angular motion such as the sea turtle and crab. Some fish use a simple flapping of the tail either for slow forward motion or for all propulsion; this motion is usually incorporated with an undulation of the complete body for high speed travel. The squid ejects water pulses in a form of jet propulsion.

Rowing, sculling, and flapping are all methods which were tried very early in the history of both manual and mechanical self-propulsion. Jet propulsion, too, dates back many years. It is the undulating method of fish propulsion which is of the most interest at the present time.

The actual motions of an undulating fish are now fairly well defined. In fact a toy fish duplicating these motions was made by the Goodyear Aircraft Company a number of years ago which performed quite well. There is still, however, a lack of understanding of the overall problem of resistance and propulsion of undulating fish.

For many types of fish on which measurements have been made, there exists no complete explanation of the apparent high horsepower output per pound of muscle which a fish can generate. A wide variety of explanations have been given involving both the resistance and the propulsion characteristics of the fish.

Some of these explanations are completely contradictory. For example, some theorists claim that the peculiar characteristics of a fish skin, or the oil which it exudes, give the fish an extremely low frictional resistance; another theory contends that the roughness of a fish skin permits it to grasp the water and work its way through in the manner of a snake moving across the ground.

August Picard recently ran a series of wind tunnel tests on thin membranes backed by resilient material, in an attempt to prove his contention that the skin of a fish accommodates itself to the flow in such a manner that it operates in laminar flow rather than in turbulent flow.

There are theories that undulating propulsion is inherently more efficient than any other method devised by man and that less "slip" exists between the propelling surface and the water. Other theorists claim a form of negative thrust deduction exists or, in other words, the resistance of the fish is decreased rather than increased by his propulsive motions. Still others claim that all measurements showing high propulsive efficiency of fish are in error, and that the fish is no more efficient than any land animal and probably less efficient than comparable man-made devices.

Even assuming this last contention to be true, the fish still has many characteristics which would be extremely beneficial to man-made waterborne vehicles. The propulsion and maneuvering mechanisms of the fish are completely integral with his body. He is ideally adapted to the environment in that he can perform all necessary evolutions rapidly without any indication of undue disturbance of the medium. His fundamental elasticity and freedom from environmental restrictions are characteristics which may, eventually, be necessarily incorporated in man-made craft if they are to exploit the sea to the utmost as an operational medium.

HYDRAULIC WHEELS

Two intensely interesting developments in the last few years have indicated that new systems of propulsion for shallow draft vessels may be both feasible and practical. Both of these developments center around the use of rotating wheels to provide dynamic lift, which can both reduce the resistance of surface craft and permit them to operate in waters of restricted depth.

The first of these developments is the *Hydroler* worked on by P. C. Lombardini and R. Fidderman of Durham, England. Quoting from their lecture at the Seventh International Congress of Applied Mechanics:

"The new theory and its application to the *Hydroler* system of propulsion is that which by utilizing a combination of buoyant body or hull, with driven rollers mounted within the hull, and with the rollers being made to retract or project from the hull on lowering the driven rollers on to the water surface, high speeds are possible.

"With the use of rollers mounted in a housing and combined with a forward motion of the housing with the rollers projecting on the water surface, it was found that drag due to the roller shape and surface tension could be overcome considerably by rotating the rollers by means of a second source of power. With the peripheral speed of the rollers, approximately equal to the forward speed of the housing, the drag is reduced by an extremely marked degree when over stalling speed.

"It is known that for any body or hull there is a certain speed up to which the optimum planing conditions hold, and above that speed the lift/drag ratio greatly decreases. However, with the application of the new theory it will be shown that this lift/drag ratio, when over stalling speed will greatly increase with an appropriate increase in speed. With such an arrangement, from stationary up to critical speed at which the effect of the Hydroler system becomes positive, the said rollers are gradually lowered to the required speed, which is a peripheral speed at least equal to that of the craft, until the rollers only are in contact with the surface of the water.

"The rollers serve the further purpose of facilitating beaching on relatively smooth beaches, as they project to the ground and support the craft therefrom; hence landing and embarking of passengers and goods may be carried out without wetting. According to the purpose for which the craft is intended the detail arrangement may be varied. The body in which the rollers are housed may be either separate from the main hull in the manner of seaplane floats, or part of the hull itself. Propulsion of the craft can be direct from power plants mounted on the floats or hull. The floats or hull provide buoyancy at zero speed and the necessary lift at forward speeds up to approximately 50 m.p.h. Above this speed, rotation of the rollers reduces water drag through centrifugal force and the zero relative velocity between the water and roller face. At the same time, since lift varies in relation to the square of forward velocity, the rollers mean draught is so reduced as to allow the floats or hull planing bottom to be raised clear of contact with the water.

"Fore and after trim may be controlled by plane and elevator similar to those used on aircraft, and likewise directional control may be effected by the use of air rudders at the fore or after end of the craft, or both. As regards synchronization of the roller drive, and control of rotational speed when rollers pass between waves, these problems are easily solved by the application of existing mechanisms.

"The second point, which at first sight appears somewhat formidable, is purely a matter of relativity. Considering only a small craft with six feet diameter rollers spaced fifteen feet apart, and travelling at 100 m.p.h., wave crests thirty feet apart would strike any one roller five times in each second. Large craft with bigger rollers would be able to similarly tackle heavier seas, but as in the case of air travel, the faster the travel also means greater facility for avoiding bad weather once a voyage is commenced."

The basic principle involved is somewhat similar to that which was inadequately stated by Knapp in regard to his rotating cylinder in 1898. One problem with Knapp's vessel, as with the other roller ships of his day, was the large surface area presented to the wind. Bazin's roller ship failed since his power source could not sufficiently overcome the water drag on the rollers. With rollers of smaller dimensions, properly protected by faired housings using powerful modern engines, such as the craft shown in Figure 14, extremely high speeds may be attainable by waterborne vehicles.

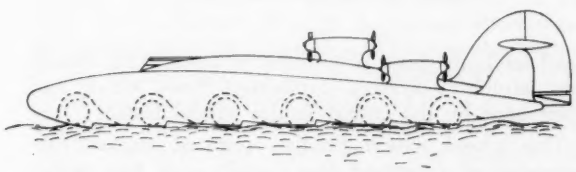


Figure 14. Proposed Design of the *Hydroler*.

During World War II considerable difficulty was experienced with small landing craft broaching in the surf as they approached a beach. One solution to this problem was to get a line ashore early in the approach so that the craft could be winched in rapidly to avoid broaching. However, this posed another problem in how to get the line ashore and secured to some fixed object far up the beach.

Governor Charles Edison of New Jersey proposed that a high speed spinning wheel, containing a reel of wire, might be launched from the craft which would run across the surface of the water and up the beach, unreeling the wire as it traveled. When the wheel got up into the underbrush the wire would become so entangled that it would be sufficiently secured to permit winching in the craft.

The David Taylor Model Basin started a series of tests on toothed wheels revolving at high speed which were launched along the surface of the basin. The launching system consisted of a curved ramp which terminated in a tangent to the water surface. The wheel was brought up to speed by a motor and then dropped onto the ramp. It rolled down the ramp, picking up horizontal velocity, and then was ejected along the water surface.

Wartime priorities enforced curtailment of this work, but in 1957 the Hydraulic Laboratory of the Newport News Shipbuilding and Drydock Company began again to experiment with spinning wheel, with the idea that they could possibly be

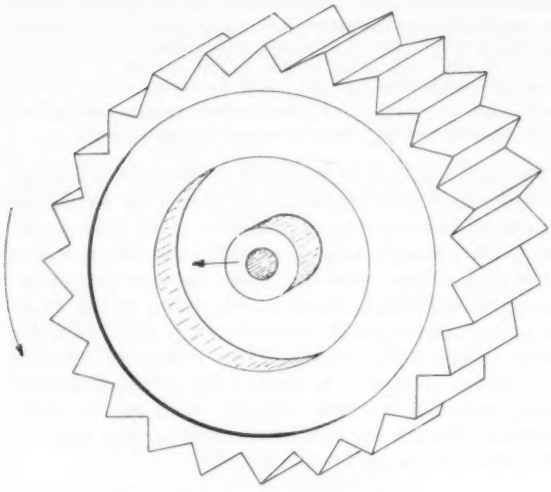


Figure 15. The Spinning Wheel.

used for high speed propulsion systems. The wheels and launching system duplicated those which had been used by the David Taylor Model Basin.

The wheel which finally operated successfully consisted of a toothed disc slightly over five inches in diameter with a face width of one inch, as shown in Figure 15. This wheel was revolved at a speed of 8320 revolutions per minute and was ejected along the water surface with a horizontal velocity of approximately eighteen miles per hour. This free spinning wheel retained this speed for the entire fifty-six foot length of the Laboratory towing tank, striking the far end of the tank with a force which indicated that it could continue to at least double that distance.

A dynamic lift is generated by this wheel but in a different manner from that which lifts the *Hydroler*. The Spinning Wheel operates on the principle once stated by Lord Kelvin that if a horse could stamp his feet hard enough and fast enough he could walk across the surface of the water. This principle permits the Spinning Wheel to retain its lift even at lowered speeds of advance; the Spinning Wheel also can propel itself, or a vehicle on which it is mounted, across the water.

The manner in which such a device might be employed in a water vehicle propulsion system cannot be determined from these very preliminary tests. However, several applications can be imagined. First, the wheel was able to support its own weight of approximately 2½ pounds. There is the possibility that a larger wheel of lighter construction conceivably could support some form of vehicle. The periphery of this wheel barely penetrates the surface of the water, indicating possible application to very shoal draft vehicles. These vehicles could be provided with high speed machinery driving the wheel, or wheels, directly, with the wheels conceivably starting from a dead start and eventually lifting the vehicle clear of the water.

It is also conceivable that this device could have wide application in ship to shore transport of either manned or unmanned vehicles. Using a ramp from the bow of a ship in a manner similar to that employed in the Hydraulic Laboratory test, the vehicle could be ejected at high speed to run, without self-contained power, to the beach.

High speed rollers appear to have a good potential for both high speed and shoal draft applications. They may also be much more adaptable to high speed propulsion machinery such as the gas turbine where large speed reductions would not be necessary in the drive system.

RIDING ABOVE THE WATER

To overcome water resistance at high speeds the tendency of designers has been to look for means to raise marine vehicles above the water surface. Some of the methods which have been either developed or are being worked on, are planing craft, hydrofoil craft, and air-cushion vehicles. The roller type vehicles described in the preceding section also fall into this category.

Probably the earliest type of craft to ride high on the surface of the water was the planing form. Abraham Morrison of Pennsylvania is often credited with the invention of planing boats with his "shin form" boat patented in 1837. Reverend C. M. Ramus and William Froude worked on planing boats in the 1870's, but little more was done with this type of craft until Glenn Curtiss and others became interested in it for seaplane floats in 1910.

Today planing motorboats are in common use throughout the world but much is yet to be learned about their performance and the finer points of design. They are chiefly of interest from a propulsion standpoint in that they require special designs of propulsive devices to operate at high speed.

The flow peculiarities under a hull which exert dynamic lift and the low pressures in the propeller area make precise design quite difficult. Small changes in trim and wave conditions can have a drastic effect on propeller performance. It is still common practice for racing enthusiasts to have a barrelful of spare propellers, which are interchanged until optimum performance is obtained.

In rough water the planing hull takes a terrific beating. Not only are the waves impinging on broad flat surfaces, but the constant loss and regaining of dynamic lift causes a pounding which can quickly demolish light structures, or at least cause extreme discomfort. One answer to this has been to immerse only small planing surfaces in the water which can lift the hull clear of disturbing waves. Vehicles of this type are called hydrofoil craft.

Hydrofoil craft had their inception in the late 1890's in France and Italy. In the United States the Wright brothers did some experimental work in

Dayton, Ohio, in 1907; and in 1909 H. C. Richardson fitted biplane hydrofoils to a canoe. Starting in 1911 Richardson and Curtiss in the United States and Guidoni in Italy worked on hydrofoils for seaplanes. Probably the most famous of the early hydrofoil craft was that built by Alexander Graham Bell and Casey Baldwin in 1918, which reportedly attained a speed of 60 knots. Some of the various types of hydrofoil craft which have been developed are shown in Figure 16.

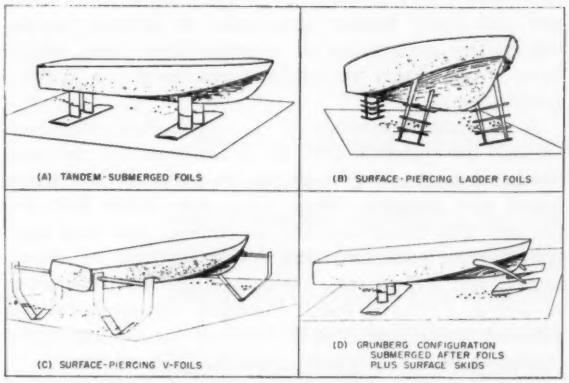

(A) TANDEM-SUBMERGED FOILS
(B) SURFACE-PIERCING LADDER FOILS
(C) SURFACE-PIERCING V-FOILS
(D) GRUNBERG CONFIGURATION SUBMERGED AFTER FOILS PLUS SURFACE SKIDS

Figure 16. Various Types of Hydrofoil Craft.

During the last forty years many types of hydrofoil craft have been tried, but up to the present time their success has been limited. This has been due to lack of good engineering materials, due to lack of light propulsion plants, and because the problems of hydrofoil flight are inherently extremely complex. Only within the last ten years, through extensive research and development, has a real understanding been gained of the dynamics of hydrofoil behavior. This has led to the design of reliable control systems and basic foil configurations which show promise of success in both military and commercial ventures.

From the propulsion standpoint the hydrofoil craft presents many problems. In order to have a screw propeller located in the plane of the bottommost hydrofoil and the machinery within the craft itself, it is necessary that right angle drives with long vertical shafts be used. The accompanying problems of mounting brackets, bearings, and bevel gears for high speed drives are obvious.

Also the performance of the craft is highly sensitive to its weight, thus requiring extremely lightweight machinery. Aircraft engines, driving airscrew propellers, show some promise along these lines, although airscrews are not economically attractive until speeds well in excess of 50 knots are reached.

Planing and hydrofoil craft rely on surfaces moving at high speed along and under the water to lift the vehicle. Another type of craft, the air-cushion vehicle, attempts to achieve somewhat the same result by an entirely different means.

The principle on which air cushion vehicles depend for levitation is that a very low air pressure maintained below a large area can result in a relatively high lifting force. This force can be sufficient to lift the vehicle with its machinery and cargo clear of the water or ground surface. Forward motion of the vehicle will then not be restricted by the frictional effects of contact with land or water surfaces.

The trick in the design of these vehicles is to maintain the air pressure at a lifting level, while in turn raising the vehicle high enough to clear ground obstructions on land and waves at sea. Two basic types of vehicles are now under development which attempt, by somewhat different means, to achieve this end result.

The first of these is the annular jet, or edge-jet vehicle. Air is taken in above the deck of the vehicle and is forced through ducts and discharged downward through a peripheral ring at the bottom of the vehicle skirt as shown in Figure 17. The jet of air is inclined inward, tending to build up a positive pressure in the enclosed space under the vehicle. Stable flow is achieved by the outward deflection of the jet balancing the internal pressure; this internal pressure in turn lifts the vehicle.

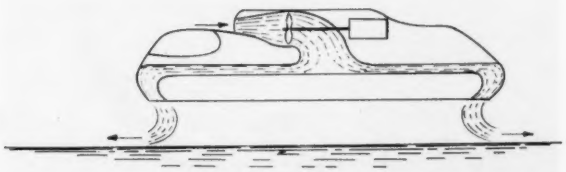


Figure 17. The Annular Jet Type of Levitating Vehicle.

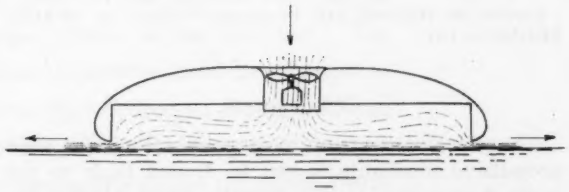


Figure 18. The Plenum Chamber Type of Levitating Vehicle.

The second kind of air-cushion vehicle is usually referred to as the plenum chamber type. As shown in Figure 18 the space beneath the vehicle is pressurized simply by pumping air into it through one or more nozzles in the deck above. As the air leaks out under the skirt it necessarily increases in velocity. An increased pressure in the plenum chamber results, which provides a lifting force to the vehicle.

The edge-jet vehicle promises the greatest height, but there is a corresponding complexity in con-

struction and an inherent lack of stability. The plenum chamber vehicle has a very simple structure and is quite stable but the height which can be achieved appears limited.

One means of propelling these vehicles is simply to transfer weights in such a manner that the skirt clearance on one side is greater than on the other. A corresponding imbalance in mass flow results which provides a propulsive thrust. This, however, is a very inefficient method of propulsion.

Airscrews seem to be the best answer to the propulsion of air-cushion vehicles or, if sufficiently high speeds are ever attained, air-jet propulsion might become economical. Since the vehicles have no inherent directional stability, it also appears that the airscrews should be steering screws to provide maneuvering control as well as propulsive thrust. An artist's conception of the marine vehicle of the future is given in Figure 19.

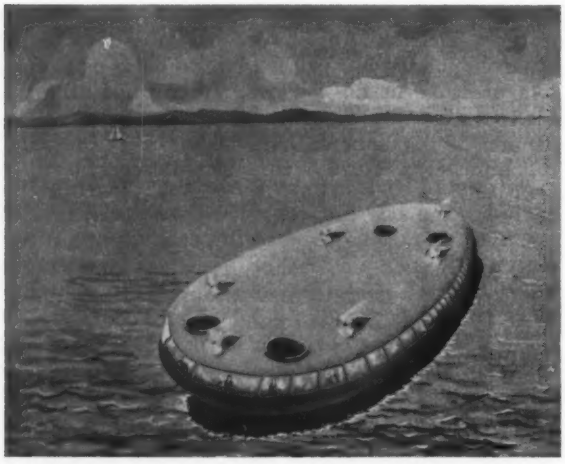


Figure 19. HYDRO-AIR Passenger Vehicle by SPACE-TRONICS, INC.

CONCLUSION

The development of marine vehicles and their propulsive mechanisms can be traced back to the earliest eras of recorded history. For centuries the ingenuity of man has been taxed to find faster and more powerful methods to move his ships through the water. Practical men and dreamers, engineers and theoreticians, have applied their talents to the solution of these ever-fascinating problems. Notable contributions have been made by the great men of science, by statesmen, by mechanics, by shoemakers, and by farmers.

Throughout all of this history of development, there has been a progressive pattern of increasing insight into the fundamental mechanisms of propulsive device behavior; this is graphically evidenced by the great size, speed, and efficiency of the marine craft which travel the oceans of the world today.

When the multitude of propulsion methods which have been devised are reviewed, it seems difficult to believe that any possibility can have been overlooked. At least it would seem that all of the basic ideas must have been exploited and that most of the conceivable variations on the fundamental schemes must have been put into practice in some part of the world. Yet even the developments within the last few years demonstrate that there are still new and untried ways to propel ships. And there are still many known principles of physics, resulting in the generation of a propelling force, which have never been seriously considered for marine propulsion.

In the past hundreds of years man has often predicted the curtailment of inventions in selected fields of technology because it seemed that there could not possibly have been any stone left unturned. Yet invention has continued, and will continue as long as there exists any freedom of imagination and any sincere desire to improve man's state of being. Perhaps these thoughts can best be expressed in the words of E. J. Reed, the distinguished British naval constructor, who in 1874 wrote:

"Any attempt at gauging the future, even the future of but a very few years, must necessarily be sketchy and incomplete. It is true of the mechanical world as of the world outside, that 'coming events cast their shadows before'; but, like the mirage of the desert, shadows are sometimes cast without the ultimate presence of the substance; and many promising discoveries, which at first appear destined to revolutionize the whole profession of the mechanic, have finally sunk into oblivion, which is the natural end of inventions lacking the stamp of practicability and commercial economy. On the other hand, where the boundary line of perfection seems nearly drawn, and there appears little to do but to gaze retrospectively upon the triumphs of the past, some great intellect arises, and with the aid of some well-timed discovery shows the world of science that the spirit of progress still lives."

ACKNOWLEDGEMENT

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Newly discovered secrets of the sun and the outer reaches of space have been reported to the American Astronomical Society by Navy scientists. The new work, relating to the existence of a great quantity of relatively cool hydrogen between the earth and the sun, was reported by Dr. Richard Tousey and James D. Purcell of the Naval Research Laboratory in Washington. Their paper described discoveries made as a result of an Aerobee-Hi rocket fired from White Sands as a part of the United States effort in the International Geophysical Cooperation, 1959, a continuing program to the International Geophysical Year.

In a previous experiment, researchers obtained photographs of the sun in the light of the penetrating ultraviolet "Lyman alpha" spectrum line of hydrogen which showed the presence of intensely emitting clouds of hydrogen scattered over the face of the sun. Analysis of the more recent experiment has resulted in obtaining what the scientists term highly significant spectra of the Lyman alpha line itself. The scientists found that the Lyman alpha line is very wide, and includes many different frequencies, both higher and lower, than ever come from hydrogen atoms in the laboratory. The width of the line, which they find to be two Angstroms, calls for a temperature of the order of 40,000 °C. This means that hydrogen atoms continue to exist in the sun far out in its chromosphere, where the temperature is extremely high. A little farther out, as the temperature rises still more, these atoms become dissociated into protons and electrons, and boil off into space. This forms the solar wind, which reaches the earth a day or two later and becomes trapped in the Van Allen belts, discovered by satellites during IGY.

—DEPARTMENT OF DEFENSE PRESS RELEASE

The Unification of the Gods

IT was bound to happen sooner or later. That Greek master of knowledge on all subjects, universally popular commentator, awesomely prolific writer, has pointed his lance at the Defense Department. His name: Anonymous *(pen name* Anon.*) His observation:*

I

Way up on the heights of Olympus
In the era before time began
Three Gods who were quite independent
Ruled over the creatures and man.
Now one had control of the oceans
The fish of the sea and the wave
He ruled in his watery kingdom
The sailors and seamen so brave.
Another was master of heavens
The clouds and the stars and the sky
The sun and the moon and the planets
And all of the creatures that fly.
The third on the earth was the ruler,
Of mountains, and deserts of sand,
Of cities, and forests, and vineyards,
And everything else on the land.
Each one to his own was the master
An so for an aeon of time
The earth and the sky and the oceans
All functioned in heavenly rhyme.

II

But just as it is with we humans
So it was with the immortal brain
They had to improve on the system
And so they began to complain:
"Just mark you, we have triplication!
It's useless, it's wasteful, and worse
We don't have our true roles and missions
Agreed on in chapter and verse."
"We're wasting the worpshippers' tribute,
By bureaucracy's tape we are tied
We'll have central procurement of nectar
We'll be much better off unified."
"One robe of a uniform fabric,
A garland of single design,
Ambrosia we singly will manage
And no one will get out of line."
"The Joint Chiefs of Status they'll call us
A body of power supreme
In cooperation we'll govern
A truly Utopian dream."

III

Alas and alack for the hopefuls
For even the Gods can be wrong
The outcome of unification
Was something quite less than a song.
"Just *who* will procure all the nectar?
And how will he be reimbursed?
What color the robe and the garland?"
Each one said that his should be first.
"Just how big a lake is an ocean?
Are frogs of the land or the seas?
Are seagulls of air or of water?
What of birds when they nest in the trees?
And what is my share of the tribute?
My Scribe always tells me I'm broke.
There's *so* much more air than there's water
And the land is so small it's a joke."
And so not a thing was decided
They all went around in a loop
The Joint Chiefs of Status were headless
And too many cooks spoil the soup.

IV

The Goddess of Discord is with us
She'll be there till the end of all time
'Tis folly to simply ignore her
Whatever the region or clime.
Since Cain had a fight with his brother
Since the Gods disagreed o'er the Ring
To a just and impartial tribunal
Our squabbles we've found we must bring.
Democracy's tenets are noble
And for them our fathers have died,
Yet ever there must be a leader
Whose function it is to decide.
In all of our human endeavor
Our strength is the way we've combined
Each man makes his own contribution
With the skill of his hands and his mind.
We still would be living in treetops
And all of our gains would be loss
If somehow we hadn't discovered
That someone has got to be boss!

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"THE SHIPBUILDER AND MARINE ENGINE-BUILDER"

TECHNICAL PROGRESS IN SHIPBUILDING DURING 1959

ACKNOWLEDGMENT

This staff article was published in the January 1960 edition of "The Shipbuilder and Marine Engine-Builder."

REPORTS from the shipbuilding industry indicate that in 1959 the number of orders for new ships were fewer than in previous years. It would appear, therefore, that while most yards still have a reasonable amount of work, the prospects for the future are not nearly so promising as they have been in the past decade or so. It is in such circumstances that technical progress in the construction of ships assumes its full importance. Advances in building techniques, which reduce the cost of production, obviously make the products of the shipyards more desirable to the shipowner. It is, therefore, pleasing to note that in British shipyards attention is still being directed towards modernization and the development and exploitation of new methods for dealing with the many problems arising in ship production.

The other side of technical progress is concerned with the production of more efficient ships, either structurally or from a resistance and propulsion point of view, or in some other respect, and the year 1959 has shown no diminution in activities along these lines.

A big step forward in the field of research was made during the year by the opening, by H.R.H. The Duke of Edinburgh, of the new Ship Hydrodynamics Laboratory at Feltham, Middlesex. This is an extension of the existing facilities of the Ship Division of the National Physical Laboratory. It is not proposed to discuss the details of this new project here, but it may be said that the facilities provided in the new establishment include a very large towing tank, a new cavitation tunnel and a sea-keeping laboratory. Since the official opening of the new laboratory, the equipment has been undergoing acceptance and calibration tests and has not been available for research during the year. It is expected that it will come into full operation during 1960. The usual investigations of model hulls and propellers have been carried out by the Ship Division during the year. As an example of the value of such work it may be noted that in several instances appreciable improvements in hull form have been achieved, and converting these improvements into fuel costs, in four cases, the estimated savings over a period of 20 years amount to over 750,000 dollars. Other cases may be mentioned where, as the result of resistance and propulsion investigations, improvements in propulsive efficiency of 40 per cent were obtained.

The reduction in the number of commercial tests during the year has resulted in more time being available for research work. The research program at present in hand does not differ greatly from that

reviewed and laid down in 1958. The program includes work on the sea-keeping qualities of ships in which observations obtained from weather ships are being correlated to laboratory experiments. Also there is work being done on propeller design and performance which has involved the making of more than 40 models. Propeller and hydrofoil cavitation are also being studied as well as resistance and propulsion on methodical series of hulls. Ship vibration plays an important part in the research program and not least of the subjects dealt with is the important one of ship model correlation.

In carrying out this extensive program of research, the Ship Division is in close touch with the British Shipbuilding Research Association, for whom many of the projects have been undertaken.

With regard to the latter organization, a brief comment in its present program of research appears appropriate. In the hydrodynamics field the work on the methodical series of ocean-going merchant vessels is continuing. The latest work has covered the effect of changing the length of parallel middle body. Another research being carried out by B.S.R.A. concerns the interdependence of skin-friction and wave-making resistances. In the field of ship structures, connections between beams and frames are being investigated largely with a view to eliminating brackets at these places. Tests have also been carried out on swedged bulkheads under lateral and column loading. A useful practical investigation concerns the most effective methods of heating cargo oil tanks. For this purpose a one-quarter scale tank has been constructed in which heating is obtained by means of a conical heating coil. The coil is being moved from place to place to find the optimum position.

Attention is being paid by the Association to the design of superstructures and funnels to ensure that decks will be kept clear of smoke. Design rules have now been formulated and have been used in the re-design of the funnel arrangements of a cross-channel ship.

The Association is still continuing to do work on the vibration of ships and their machinery, and a particular aspect of this is axial vibration of shafting. The correct determination of criticals for this type of vibration is bound up with the stiffness of the thrust block seating and work is being done on this problem.

Finally in the B.S.R.A. research program, studies of the application of nuclear power to the propulsion of ships are being continued, and the Association has contact with the Atomic Energy Authority establishments at Risley and at Harwell and Winfrith Heath.

STRUCTURAL STRENGTH AND WELDING

The first piece of work which we shall review under this heading has been published in a paper by Professor E. V. Telfer, D.Sc., Ph.D.[1] It concerns the longitudinal strength of ships and the object of the author's work is to show how the 1915 Load Line Committee's statistical approach to the longitudinal strength modulus of ships can be further developed by means of a non-dimensional treatment. It is claimed that this simple approach enables current knowledge to be extrapolated safely to the largest ships at present contemplated. It will be remembered that the formula produced by the Load Line Committee for the value of Z of the midship section is $Z=fdB$, where d is the draft and B the breadth, f being a coefficient which varies with length. Professor Telfer proposes a formula given in non-dimensional form as follows:—

$$Z/BL^2 = \frac{200}{10^6} \times d^{2/3}$$

Professor Telfer goes on to discuss the question of the wave-bending moment and the stresses likely to be encountered under sea-going conditions. He suggests that the greatest wave stress is not likely to exceed $\frac{10-s}{3}$ where s is the still-water stress. He also states that the effective wave height can be given by the formula $H = \frac{20L}{200+L}$. The wave bending moment of all ships is considered to be

$$M_w = 440\,B\,L^2 d^{2/3}/10^6 \text{ tons-ft.}$$

giving a standard wave bending moment of three times the value or

$$M_t = 1320\,B\,L^2\,d^{2/3}/10^6 \text{ tons-ft.}$$

Where the standard still-water bending moment of $880\,B\,L^2 d^{2/3}/10^6$ tons-ft. is exceeded by X per cent, the standard modulus should be increased by two thirds of this percentage.

Another interesting piece of research work on ships' structures has been published by Mr. I. M. Yuille, B.Sc., Ph.D.[2]. The purpose of the work was to decide which of the variations of the elastic bending theory are important in shipbuilding and to formulate a convenient method of analysis which would give reasonable values of stresses and deflections. The investigation was facilitated by information made available by the large series of tests carried out for the British Shipbuilding Research Association at Glengarnock. The author has developed theories to take into account the variation in cross section along the length of a beam, the stiffness of the structure at the ends of the beam and the twisting of beams having non-symmetrical cross sections. He has demonstrated that, if such theories are used to calculate the stresses and deflections for welded beams, results are obtained which are sufficiently accurate for practical purposes, provided that adequate data are available about the stiffness of the structure at the ends of the beams. The work re-

corded in this paper should assist in extending the knowledge of the behavior of structural members.

Great interest has been shown in recent years in the carriage of gases in the liquefied form in special vessels. This involves very low temperatures and, in consequence, the behavior of the material of the container at these low temperatures has to be very carefully considered. Naval architects will, therefore, be interested in a paper on this subject published in the United States of America.[3] The authors of this paper are dealing with the problems involved in the use of steels for such projects. To obtain some idea of the problem involved it may be mentioned that in the carriage of liquid methane the temperature goes down as low as −258° F. As is well known, the properties of ordinary mild steel at low temperatures are very critical so that to obtain a suitable material for use under such conditions special steels have to be considered. Apparently the nickel steels are very suitable in this respect and from the work discussed in this paper arbitrary limits as to the lowest service temperature for the use of the various nickel steels have been established. These are as follows:—

2¼ per cent Ni	−75°F.
3½ per cent Ni	−150°F.
9 per cent Ni	−320°F.

Stainless steel also shows very good properties and apparently it is possible to go down to −452° F with the types known as 304 and 304L. The nickel steels also show good fatigue properties which is another important consideration.

The above notes give only a brief account of the valuable information which is to be found in this paper, and those who are interested in the design of structures at reduced temperatures should consult the original where many other important aspects of the problems are dealt with.

With regard to methods of welding structures, we would draw the attention of our readers to two papers to be found in the *British Welding Journal*[5, 6]. Both of these papers are concerned with the making of vertical welds by automatic means and while it would appear that they are probably best suited for very thick plating of the order of 2 inches, it would seem that they should have some application to the welding of heavy plating in shipbuilding. The first of these papers describes the development of the Russian electro-slag process from submerged-arc welding. The principal problems involved with these methods for making vertical welds are the maintenance of uniformity of finish and the difficulty of obtaining welds free from slag inclusions due to the natural tendency for molten slag to float to the top of the weld pool. With these systems there is generally no means of varying the vertical rate of travel so that variations in preparation, or any tendency for weld metal to fall off under the influence of gravity, will lead to lack of uniformity and unsatisfactory welds. The application of submerged-arc welding is the basis of the vertical welding method pioneered in the U.S.S.R. and has been termed the "electro-slag process." The arc is initiated on a run-on plate and after this the current passes through the top of the electrode to the surface of the molten weld pool through molten slag. The pool is contained between the faces of the joint by damming blocks which are traversed up the joint, together with the wire feeder, as metal is deposited. As an example of the test results which can be obtained with 1 to 2 inch thick boiler quality mild steel plate, the yield stress was 24.3 tons per square inch and the ultimate 34.4 tons per square inch with an elongation of 30 per cent.

The second of the papers referred to deals with the Rockweld-Vus Vertomatic electro-slag welding machine. This differs from the Russian machine in having articulated water-cooled shoes, automatic control of the shoe motion and flux feed, and in using a special composite wire. As an indication of the speed which can be achieved with this welding machine it may be noted that with 2-inch thick plating the welding rate was 3 to 4 feet per hour. Tests on material welded showed a tensile strength of 34 tons per square inch with an elongation of about 30 per cent. There are very many features of interest in this welding machine and we would recommend readers to examine the original paper for further information.

Two British Welding Research Association reports on welded connections between I-section beams and stanchions should have some interest for shipbuilders.[7, 8] The work is not directly concerned with ship structures and in fact deals with the connections in steel-framed buildings. The interest, however, so far as shipbuilding is concerned, is that the connections of beams to vertical members in the specimens tested are made without the use of brackets, which is usual practice in shipbuilding. The evidence of the tests appears to be that efficient connections can be made without brackets. The bracket is more or less a hang-over from the days of riveting and is quite unnecessary when welding is employed. In the other hand, it should be pointed out that the bracket gives a greater degree of license in the fitting of the parts, whereas if beams were simply butted to the outstanding flanges of frames in a ship then much more accurate fitting would probably be necessary in order to obtain satisfactory welds.

An interesting comparison of steel and aluminum has been made on a relatively simple structure, *viz.*, a hatch beam, in a paper read before the Institution of Engineers and Shipbuilders in Scotland.[9] This work was carried out by the British Shipbuilding Research Association. A steel hatch beam was designed and an exactly similar one was constructed of NP5/6 aluminum alloy. No attempt was made to design an equivalent aluminum beam. The intention was to test the steel and aluminum beams, both of the same scant-

lings, under the same loading conditions. The tests showed that the aluminum beam was as efficient structurally as its steel counterpart. Further tests showed that it was possible to re-design hatch beams so as to make a more efficient use of the material. This was achieved by maintaining a uniform web depth over the center portion of the beam instead of having a straight taper from the center to the ends.

To conclude this section we refer to another report from the British Welding Research Association, this time dealing with fatigue tests on aluminum alloys[10]. These tests were of the pulsating tension type and were carried out on specimens of HE30 and NP5/6 containing transverse butt welds made by the argon arc and self-adjusting arc processes. The specimens are ¼-inch thick and it was decided to limit the investigation to 2×10^6 cycles. In addition to the main tests made with the two welding processes already mentioned, some specimens were introduced which had been welded by the metal-arc process. The investigation is not yet complete but the results, so far obtained, are summarized in Table I. These are compared with results from Alcoa.

TABLE I

Specimen type (He.30 and 61.S-T)	Fatigue Strength at 2×10^6 cycles, tons per sq. in.				
	BWRA (HE.30)	ALCOA (61.S-T)	BWRA (NP.5/6)	NCRE NS.6 (NP.5/6)	ALCOA (A 54 S)
Plain material	10	70			
Argon-arc welds made from one side	3.5—6 reinforcement on	3.3—5.3 reinforcement on and off	12	8—10	—
and from both sides			5—7.5	—	—
Self-adjusting arc welds made from one side	3.5—5.5 reinforcement on	—	3.5—5.5	4.6—5.0	3.4—5.4
			—	5.6—6.4	
Self-adjusting arc welds made from both sides	5.5—7 reinforcement on and off	2.5 warped specimens —	—	2.7—3.7	—
Metal-arc welds made from one side	3—4.5 reinforcement on				
Metal-arc welds made from both sides.	—	2.9—3.6 reniforcement on and off			

RESISTANCE AND PROPULSION

Several valuable research studies have been made available during the year in this field through the medium of the transactions of the various technical institutions. We shall consider first an analysis made by Mr. D. I. Moor, B.Sc., and Miss V. F. Small of the effective horsepower of single-screw ships[11]. This work, which was published in a paper to the Institution of Naval Architects, is an attempt to summarize the results in this country of model experiments since the introduction of artificial turbulence stimulation devices. The results are put in the form of a series of charts of © for a ship having dimensions of 400 feet LBP, 55-foot beam and 26 foot draft. They are presented for a series of speeds, positions of the center of buoyancy and block coefficient. To illustrate what has been done we reproduce in Figure 1 one of the charts for a value of $V/\sqrt{L}=0.60$. Diagrams similar to this are reproduced for values of $V/\sqrt{L}$ from 0.50 to 0.90. The use of the diagrams is self explanatory and requires no further comment. The results refer to average values and it is stated that the best forms available at present will give values of © some 3 to 5 per cent less than the average values. The data

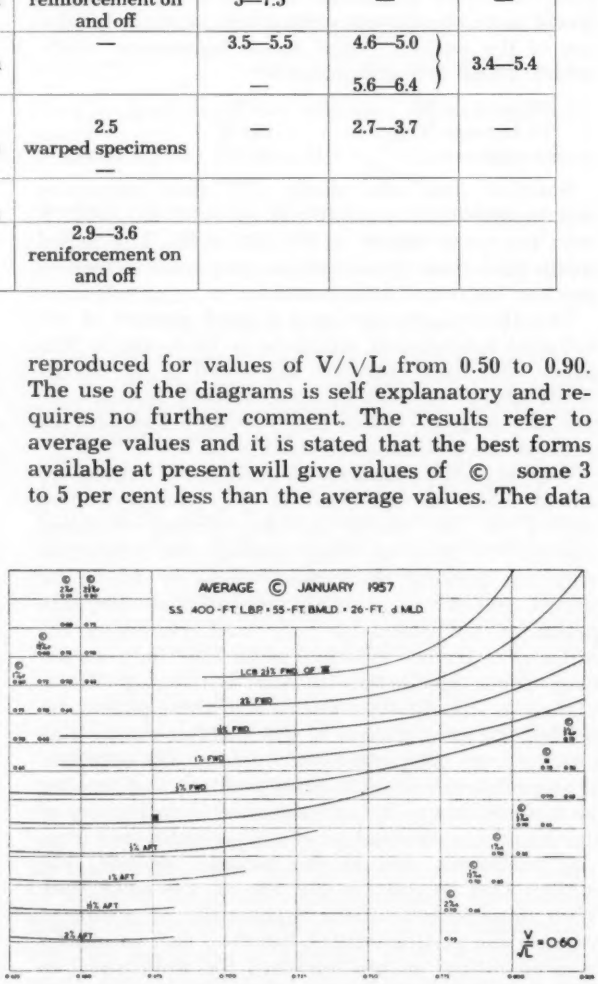

Figure 1. $V/\sqrt{L}=0.60$.

presented in the main body of this paper was that available in January, 1957. Since that time the results from an additional 200 models became available. These later results did not make any marked differences in the ones originally produced at low and medium speeds for vessels below C_B=0.75. On the other hand, many of the new values for fuller vessels with LCB well forward of amidships lay below the 1957 curves. The curves were, therefore, adjusted in this region and reductions of the order of 2 per cent for normal tanker proportions were obtained.

On the theoretical side of ship wave resistance we would refer to a paper by Professor Dr.-Ing. G. P. Weinblum[12]. This is not a theoretical treatise on the wave resistance problem, but rather an assessment of the value of the theoretical work in so far as the design of ship forms is concerned. Professor Weinblum reviews the basis of the theoretical formulae for wave resistance and draws attention to the discrepancies between theory and experiment. As an instance of the way in which theory can help in the design of form, it might be noted that progress has been made in the understanding of the problem of the optimum longitudinal position of the center of buoyancy. Tables have also been prepared which permit calculations to be carried out to assess the relative value of U and V shaped sections. The advantage of U shaped forms has been established which is in agreement with experiment. Other aspects of the resistance problem, which are discussed in this paper, include the empirical corrections which have to be made to help bring theory and experiment into line. Also the application of theory to submerged bodies and to planing and hydrofoil craft is dealt with. The influence of the propeller in ship propulsion is touched upon and, it is interesting to note, that the wave system created by the propeller can produce an appreciable interference effect with the ship-wave system. It is suggested that it is advantageous to locate the propeller in the region of a hull wave crest.

A practical aspect of the ship model problem has been dealt with by Mr. A. Emerson, M.Sc.[13]. This concerns the question of size of model in relation to tank size. The problem became evident some years back when it was shown that the cross section of the model produces an increase in the velocity of the water past it when it is towed in the tank. This increase is over and above any increase in velocity due to the shape of the hull and is due to the fact that because of the reduction in cross-sectional area of the water in the tank in way of the model the water velocity, relative to the model, must increase to maintain continuity. The effect has often been referred to as "blockage" and the increase in mean velocity can be given as

$$\frac{\delta v}{v} = \frac{a}{A - a - \frac{bv^2}{g}}$$

where

A = cross-sectional area of tank
a = cross-sectional area of model
b = breadth of tank at water surface
v = speed of model, and
δv = the average increase in the speed of the water around the model.

A second effect occurs, *viz.*, a sinkage in the water surface which can be expressed by

$$\delta h = \frac{(v+\delta v)^2}{2g} - \frac{v^2}{2g}$$

$$= \frac{\delta v}{v} \times \frac{v^2}{g}.$$

The author of this paper carried out a whole series of experiments at King's College, Newcastle-on-Tyne in which tank size was varied, the resistance of a model at various speeds being determined with different tank cross sections. Figure 2 shows the type of result obtained from these experiments. The marked increase in resistance as the tank becomes smaller will be obvious from this diagram.

It is suggested by the author that small errors due to differences in proportions of model to tank could be eliminated by stating the blockage correction for all tank results. Apparently in ordinary merchant ship tank testing the correction is small but tends to become important in trawlers and coasters.

For those who want to keep in touch with the hydrodynamic research, in progress throughout the world, a paper by Mr. F. H. Todd, B.Sc., Ph.D., of the Ship Division of the National Physical Laboratory will be of interest[14]. The subjects covered in this survey of world research include ship resistance and propulsion, extrapolation of model results, correlation of model prediction and service performance, sea-going qualities of ships, and ship vibration. One of these items, *viz.*, the sea-going qualities of ships, is a relatively new research, although in the past few years a great deal has been published on this subject. In this respect the work of oceanographers has been very helpful and the statistical analysis of records of the condition of the sea made on board ship should eventually enable the performance of a ship to be predicted in any given sea.

We have had occasion in previous years to refer to work on the resistance and propulsion of coasters. A further contribution to this subject has been made by Mr. J. Dawson, B.Sc., during the year[15]. In this paper the results for a third series of coaster

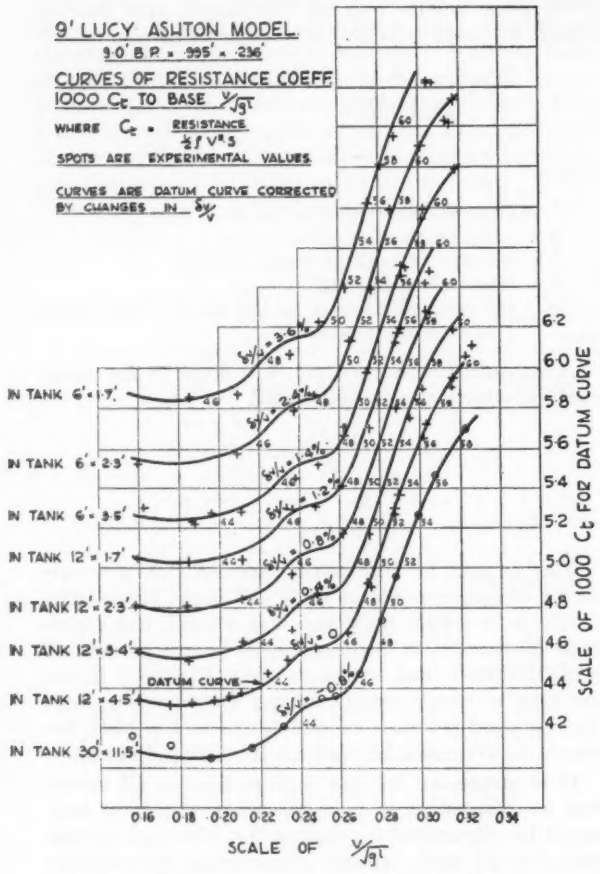
9' LUCY ASHTON MODEL.
9·0' B.P. = ·995' × ·236'
CURVES OF RESISTANCE COEFF. 1000 C_t TO BASE $V/\sqrt{gL}$
WHERE C_t = RESISTANCE / $\frac{1}{2}\rho V^2 S$
SPOTS ARE EXPERIMENTAL VALUES
CURVES ARE DATUM CURVE CORRECTED BY CHANGES IN δ/∇
IN TANK 6' × 1·7'
IN TANK 6' × 2·3'
IN TANK 6' × 3·5'
IN TANK 12' × 1·7'
IN TANK 12' × 2·3'
IN TANK 12' × 3·4'
IN TANK 12' × 4·5'
IN TANK 30' × 11·5'
DATUM CURVE
SCALE OF 1000 C_t FOR DATUM CURVE
SCALE OF $V/\sqrt{gL}$

Figure 2. Plotting of Resistance Coefficients from 9 foot "Lucy Ashton" model.

models is dealt with and this completes the basic plan of research for this type of vessel being carried out by the National Physical Laboratory. The factors investigated in this series were the influence of block coefficient, position of LCB, midship area and draft upon resistance. The effect on the propulsion characteristics of block coefficient, position of LCB and speed were also examined, one propeller being used at a constant load draft. The model hulls in these experiments had a value of L/B of 5.5 and they represented to a 1/12 scale a 200-foot ship with a load draft of 15 feet. Block coefficients of 0.65, 0.70 and 0.75 were tested each with four positions of the center of buoyancy giving a total of 12 models in all. These models were tested at three drafts on a level keel and at one draft with a trim of 5 feet by the stern for the full size ship. The results obtained from these latest experiments with those from earlier tests provide comprehensive data which should assist greatly the designer of this type of vessel.

We would draw attention to some work which is of interest from a resistance and propulsion point of view and also from the point of view of ship vibration. This concerns the calculation of the pressure field round a marine propeller and is contained in a paper read at the November meetings of the American Society of Naval Architects and Marine Engineers[16]. Previous work on the calculation of the blade frequency pressure field about a ship propeller was incomplete in that only the field due to thrust and torque was considered. The present paper deals with the total field produced by blade thickness effects as well as that due to loading. Comparison with experimental results for one model of a ship propeller shows that this complete theory now explains the observed axial pressure phenomena and gives satisfactory agreement with the data obtained over a range of tip clearances. In particular, good agreement was obtained concerning the variation of the blade frequency pressure with tip clearance from the hull. The drop in the pressure coefficient is very marked with increase in tip clearance up to about 0.15 D, where D is the propeller diameter.

Another paper read in America concerns the shape of the after body on propulsion[17]. This gives the results of a comprehensive series of experiments which have been carried out by the Netherlands Ship Model Basin on this problem. The work was inspired because of the cavitation erosion troubles which had arisen in high-powered tankers. The basic type of ship which was investigated was a 39,000 ton deadweight tanker. No less than seven variations in after body arrangement were studied and these were (1) optimum shape from an efficiency point of view, (2) extremely V sections, (3) extremely U sections, (4) cigar shaped stern, (5) extremely U sections with a screw in a nozzle, (6) extremely U sections combined with two screws each fitted in a nozzle one above the other, and (7) a twin-screw arrangement. Resistance and propulsion tests were carried out with four and five-bladed propellers in the loaded and light conditions. Wake measurements with pitot tubes and flow observations with tufts were made. Cavitation tests were also carried out in the tunnel with adjustable flow. It is not possible to summarize briefly the results of these valuable experiments. However, neither alternatives (2) or (6) could be recommended, although alternative (3) is considered to be acceptable. The other alternatives have various features in their favor depending upon what is considered to be important in any particular problem. Further research is to be made into this extremely interesting and important subject.

The problem of correlation of ship and model data has been the subject of discussion during the year[18]. The big problem in such work is to extrapolate correctly the model frictional resistance to the full-size ship or, in other words, to find the correct slope of the curve of skin friction coefficient C_f to a base of Reynolds Number. To this end the International Towing Tank Conference produced, in

1957, a "line" which is now known as the 1957 I.T.T.C. Line. This can be expressed by the following formula:—

$$C_f = \frac{0.075}{(\log_{10} R_N - 2)^2}$$

The work of ship correlation dealt with in reference 18 has been based on this line. The results of trials of ships of two classes "A" and "B" were analyzed in this way. Class "A" refers to trials where good measured mile results were obtained. Class "B" refers to ships under the same measured mile conditions, except that the trial was run more than 20 days after the ship had last docked. Using the I.T.T.C. line the average percentage to be added to ships of Class "A" to give the trial power is 7 per cent with a total scatter of 16 per cent, and for ships of class "B" the percentage is 18 with a total scatter of 32 per cent. That this line is not the complete answer to the problem is evident from the figures quoted, and it would appear that the error must lie in the incorrect assessment of roughness. Until the roughness of a ship can be definitely calculated in a particular case and its influence on the frictional resistance determined, inconsistencies are bound to exist no matter what frictional resistance line is used.

The detection of turbulence has been the subject of an investigation recorded by Mr. R. L. Townsin[19]. The three methods previously available, *viz.*, chemical paint, ink stream, and hot wire anemometry were all too cumbersome for easy use and a simple alternative technique has been developed at King's College, Newcastle-on-Tyne. The sensing elements in this method form part of the model surface and do not obstruct the flow. The method is somewhat similar to hot wire anemometry but uses a hot platinum film. The results obtained in three models show the need for flow studies during the testing of small models and during the testing of large models at low speeds.

Full scale data on ship trials is invaluable to the naval architect and the profession is indebted once again to Professor G. Aertssen[20]. It is not possible to discuss in any detail the results given in this paper, but perhaps some of the general conclusions may be of interest. The first of the two ships was a passenger cargo liner and, from measured mile results run after six months of service, it appears that the rate of increase of power due to fouling is 2 per cent per month, although it is expected that this would decline after six months service. On the other hand the tanker showed only 4 per cent increase in power after two years service. Neither ship showed any very large loss of speed in rough weather. The figure could be taken as 11 to 12 per cent loss in a Beaufort 6 sea. It would appear that a good average figure for the increase in power due to rough weather would be about 15 per cent.

Our last reference in the resistance and propulsion field concerns the resistance and propulsion of trawlers[21]. This is a statistical analysis of all resistance data obtained for trawlers in the No. 1 tank in the Ship Division of the National Physical Laboratory. The E.H.P. calculations can be made by determining six parameters from the normal ship's lines. It is of interest to note that to facilitate this work a program was prepared for a digital computer (the DEUCE type) so that an E.H.P. estimate can be made very rapidly for a given set of parameters. The six parameters used are length/beam ratio, beam/draft ratio, midship area coefficient, prismatic coefficient, longitudinal center of buoyancy and the half angle of entrance. A formula is evolved for the resistance coefficient $C_R = \frac{R \cdot L}{\Delta \cdot V^2}$, where R is the resistance and L the length of the ship. This expression contains no less than 30 terms, but with the aid of the computer this can be readily evaluated. Also included in this paper are data concerning the propulsion of trawlers. Propeller data are available both in open water and in the cavitation tunnel in both non-cavitating and cavitating conditions. From these results the most suitable propeller for free running and for trawling conditions can be determined. Propulsion factors for design and estimating purposes have also been derived from the data available.

STABILITY, SHIP MOTION AND VIBRATION

In this field we would mention first of all a paper by Professor M. Yamagata, Dr. Eng.[22]. This is an attempt to assess a standard of stability for ships, taking into account all the factors which are likely to be important under sea-going conditions. Thus in assessing the stability of a ship the effect of wind, waves, shipping of water, shifting of weights, and steering are taken account of. On this basis a method is developed for determining a suitable value of the metacentric height.

Another useful piece of work on seaworthiness has been recorded by Mr. R. N. Newton, R.C.N.C.[23]. Here the question of wetness of a ship is being considered when moving through a sea. The particular features of the ship form considered in this respect are the freeboard and flare at the forward end. The work is an analysis of model experiments on hulls in regular waves and shows, among other things, that for a specified annual incidence of wetness the freeboard coefficient should increase up to a critical length of ship after which it should decrease for ships of greater length.

Another aspect of the seaworthiness problem is the possible reduction in pitching motion to be achieved by the use of anti-pitching fins. This has been dealt with by Mr. M. A. Abkowitz[24], who has carried out experiments and done a great deal of theoretical work on this subject. He has shown that

the pitching motion of a ship can be reduced to one half by the use of moderately sized anti-pitching fins at the bow. The forces involved on the fins are not such as to require an abnormal type of structure.

A new aspect of the ship vibration problem has been dealt with in the United States of America[25]. This is the question of hull vibration excited by rudders. It was discovered on U.S.S. *Forrest Sherman*. The vibration was of the horizontal three-node type and was present over a wide range of shaft speeds. The Boston Naval Shipyard traced the vibration to the twin rudders and eliminated it eventually by a reversal of the toe angle setting. In the paper to which reference is made the author explored several conceivable explanations and accounted for the phenomenon as being due to a subcritical control surface flutter condition.

DESIGN OF SHIPS

In this section we shall deal very briefly with some of the literature on design problems which has been published during the year and also on some problems of general interest to shipbuilders and shipowners.

In the field of design we refer first to a study of a nuclear-powered cargo liner[26]. The study is for a ship of about 12,600 tons cargo deadweight with a speed of nearly 20 knots. The economic survey suggests that the nuclear-powered ship is nearly as attractive as the conventional ship.

Another design investigation, which might be mentioned, concerns nuclear-powered submarine cargo vessels[27]. The conclusion from this investigation appears to be that, at the present time, although the project is feasible, it is unlikely to be economic and only some very special circumstances would justify the adoption of such a ship.

The design of cargo container ships has also been discussed during the year[28]. A detailed study of the problem is given in this paper and designs for several different types of vessels are to be found therein.

Designers of the train ferry type of vessel will be interested in a paper on this subject by Mr. J. P. Campbell[29]. The history of the vessel is dealt with and the details of the latest types are given.

An entirely new type of craft which has come into being recently is the Hovercraft, and a paper on the subject has been presented to the Institution of Naval Architects[30]. The principle used by the craft is the development of an air cushion having a pressure higher than atmospheric. This is bounded above by the undersurface of the craft, below by the surface over which the craft operates, and at the sides by an air curtain. The air curtain is produced by ejecting air from the undersurface of the craft through a nozzle which extends round the whole of the perimeter. A Hovercraft has been built experimentally. It is clear that there are many possibilities with such a device and time will tell if these can be exploited successfully.

Some particulars of the design of a trawler for research purposes are to be found in a paper given to the Institution of Naval Architects[31]. The ship described is a Portuguese vessel and is of the stern fishing type.

At the spring meeting of the American Society of Naval Architects and Marine Engineers what was virtually a symposium on ice-breakers was presented in the form of six papers. We include these in the list of references for those who are interested[32]. The papers cover a wide range of problems, both in the design and operation of these craft.

MISCELLANEOUS TOPICS

Turning now to some miscellaneous topics, we would mention first a study of acoustical problems on board ship by Mr. J. West, B.Sc., and Mr. D. G. Smart[33] which should be useful to those concerned with passenger ship design.

Then we make reference to an American paper describing the development in the submarine since the Second World War[34].

On the practical shipbuilding side attention is drawn to a paper on dry-docks[35] in which the need for bigger docks is emphasized, another paper on optical marking (a subject which may greatly modify traditional shipbuilding methods)[36], an American paper on ship maintenance and repair[37], and a fourth paper on the preparation of plates[38].

Finally we make reference to four other papers respectively on mooring anchors[39], tonnage measurements[40], ship losses[41], and oceanography[42].

In all of these papers, although some are not directly connected with everyday shipbuilding, designers and builders should find much of interest.

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    (*ii*) "Design and Construction of Icebreakers," by Mr. J. Gordon German.
    (*iii*) "Stability and Control of H.M.C.S. *Labrador*," by Construction Captain F. W. Matthews, R.C.N.
    (*iv*) "Application of Nuclear Power to Icebreakers," by Mr. S. W. Lank, and Mr. O. H. Oakley.
    (*v*) "Operation of Department of Transport Ice-breakers in Canada," by Mr. A. Watson.
    (*vi*) "Technical Aspects of Icebreaker Operation," by Rear Admiral E. H. Thiele, U.S.C.G.
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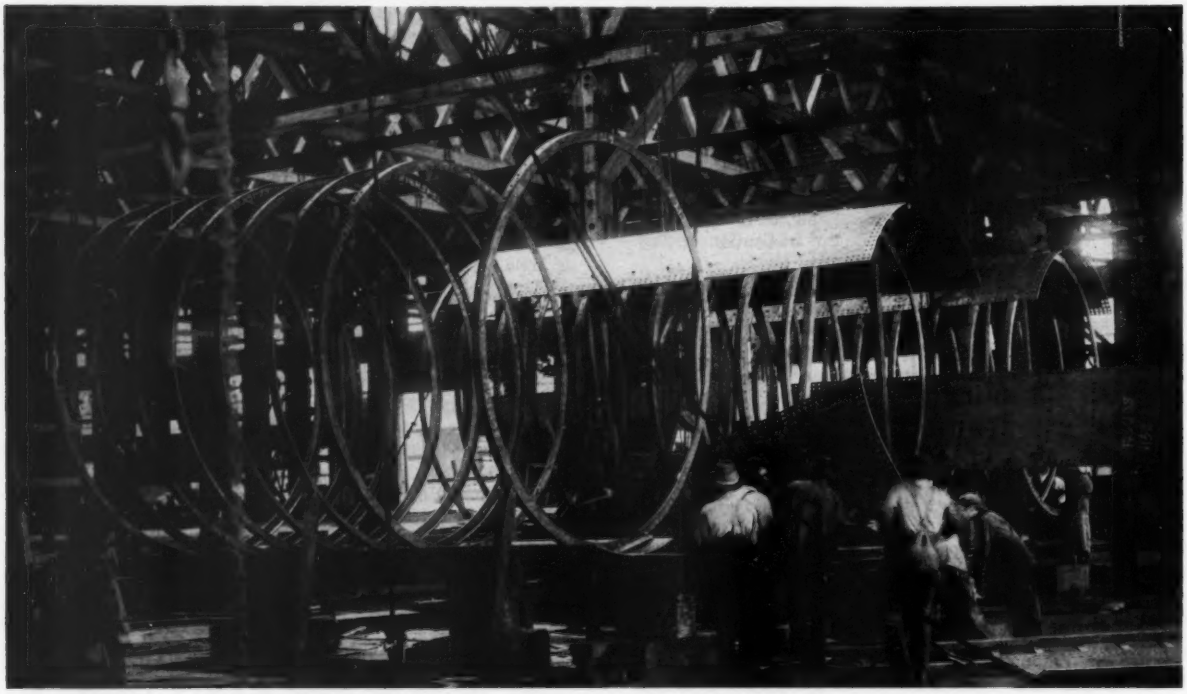
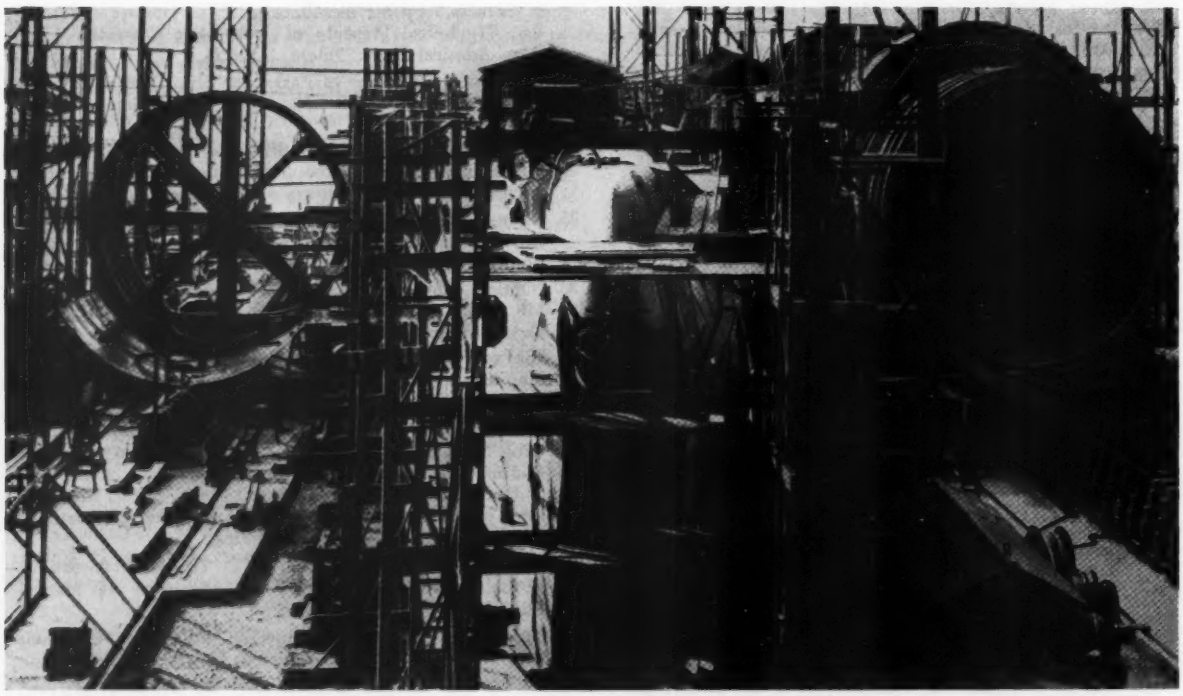
Triplets—50 Years Apart



Assembly of three submarines in Newport News Shipshed in 1904. Shell plate in process of attachment to ring frame.



Three of the nuclear-powered submarines in the Navy's atomic building program are shown side by side on the building ways of the Electric Boat Division of General Dynamics Corp. at Groton, Conn. The photo is recently released of the atomic trio—(from left) *Skipjack*, *Skate* and *Triton*. *Skipjack* is the fastest sub ever built and *Triton* the largest. The marriage of atomic power and whale-like hull design makes *Skipjack* a virtual "flying" submarine while *Triton* incorporates twin nuclear reactors for super power to propel the mammoth radar picket station.

COMMANDER M. H. DIXON

AN ANALYSIS OF THERMOELECTRIC EFFECTS

THE AUTHOR

recently acting as Project Manager for the Thermoelectric Power Program at the U. S. Naval Engineering Experiment Station, Annapolis, Maryland, is presently on duty as Inspector of Naval Material, Cincinnati, Ohio. Other recent duties include those of Assistant to the Head of the Machinery Design Branch in the Bureau of Ships for aircraft carriers and for nuclear power cycles.

PUBLISHED TECHNICAL literature has provided many articles and reports on the subject of thermoelectric power. Power generators, cooling devices, and materials have been well covered. However, in the main, they are written for readers who already know a great deal about the subject, and as a consequence, the reader who is interested but not expert may, more often than not, find himself lost for lack of the basic background essential for understanding. An investigation into the "what, how, and why" of thermoelectric effects would cover a considerable part of the fields of atomic physics and advanced mathematics and would require much sorting of facts to determine what is essential to the subject of thermoelectric effects and what is extraneous. This article is an attempt to present the results of a mechanical engineer's quest for basic knowledge of thermoelectric effects. It is presented in the hope that it may save others the hours of digging and sorting necessary to sort out the facts and theory for a modicum of understanding.

Thermoelectric effects have been known since 1822 when Seebeck described what is now known as the Seebeck effect in the Reports of the Prussian Academy of Sciences. In the course of his experiments, Seebeck compiled an extensive thermoelectric materials series. If he had been able to construct a thermoelectric generator with the first and last of the materials in his series, PbS (lead-sulfide) and SbZn (antimony- zinc), he could have obtained an efficiency of 3 per cent—as much as the steam engines of his day. One can only wonder what may have been the effect had as much time and effort been expended on the development of thermoelectric power as on steam power. Our electric power generation equipment may have been entirely different.

Since then, two other thermoelectric effects have been discovered—the Peltier effect in 1834 and the Thomson effect in 1857. These three effects cover the known field of thermoelectricity.

The Seebeck effect is a thermoelectric voltage (dE) which appears in an open circuit consisting of two different conductors when there is a temperature difference (dT) between their ends. This may

LIST OF SYMBOLS

Symbol	Description	Units
a	Seebeck coefficient	volt/°K
A	cross-section area normal to the direction of the heat flux	cm^2
e	electron charge	volts
E	thermoelectric emf at load terminals	volts
F	electric field strength	erg/volt
h	Planck's constant (6.625×10^{-27})	$\frac{\text{gram-cm}^2}{\text{sec}}$ or erg-sec
I	load current	ampere
k	specific thermal conductivity	watt/°K−cm
k_w	wave number	cm^{-1}
K	kA/X	watt/°K−cm
m	electron mass	gram
m_R	ratio of external to internal resistance: $\frac{R}{r_P+r_N}$	—
M	$\sqrt{1+\frac{1}{2}(Z)(T_h-T_c)}$	—
N(ε)	number of electrons with energy ε	—
p	momentum	gm−cm/sec
P_o	useful electric power	watt
Q_P	Peltier heat	watt
Q_J	Joule heat	watt
Q_T	Thomson heat	watt
r	r_P+r_N	ohm
r_P	electrical resistance P-type material	ohm
r_N	electrical resistance N-type material	ohm
R	external resistance	ohm
R_T	total resistance ($R+r_P+r_N$)	ohm
S	entropy	watt-sec/°K
T_h	hot end temperature	°K
T_c	cold end temperature	°K
u	electron velocity	cm/sec
U	wave velocity	cm/sec
W	potential energy	electron volts
X	thermoelement length	cm
Z	figure of merit	cm^{-1}
ε	energy of electron	ergs or volt
η	efficiency	—
λ	wave length	cm
Π	3.1416	—
Π*	Peltier coefficient	volt
ρ	electrical resistivity	ohm-cm
τ	Thomson coefficient	volt/°K
ϕ	heat flux	watt/cm^2
ψ	wave function	—
$\nabla^2\psi$	$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2}$	cm^{-2}

be described by the equation:

$$dE=a\,dT \text{ volts} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where "a" is a coefficient commonly known as the Seebeck coefficient. The Peltier effect is heat (dQ) generated, or absorbed, at the boundary between two different conductors when a current (dI) flows through them. The Peltier effect may be described by the equation:

$$dQ_P=\Pi^*dI \text{ watts} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where Π^* (pi) is the Peltier coefficient. The Thomson effect is heat (dQ_T) generated or absorbed by a current dI in a homogenous conductor, with a length dx, in the presence of a temperature gradient $\partial T/\partial x$. The Thomson effect may be described by the equation:

$$dQ_T=\tau\,dI\frac{\partial T}{\partial x}dx \text{ watts} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where τ (tau) is the Thomson coefficient.

Thus, if one considers a closed circuit composed of two different conductors with a temperature difference between the junctions as shown in Figure 1, three thermoelectric phenomena occur: (1) the Seebeck potential is manifested as a current due to the thermoelectric voltage across the external resistance R, (2) the Peltier effect occurs as an absorption or generation of heat at the junctions due to the flow of current, and (3) the Thomson effect occurs as the generation or absorption of heat along the length of the legs (1 and 2) due to the flow of current. The generation or absorption of heat in the Peltier and Thomson effects depends upon the direction of the current which, in turn, depends upon the relative magnitude of the Seebeck effect in each leg.

There is a definite relationship between the Seebeck coefficient a, the Peltier coefficient Π^*, and the Thomson coefficient τ. As developed later, each of these three effects are different manifestations of the same basic phenomena, the flow of free electrons and holes in the thermoelectric materials caused by a temperature gradient. Under steady state conditions, according to the law of conservation of energy, all types of energy generated in the circuit must sum up to zero. The two ends of conductors 1 and 2, being at different temperatures, will generate a thermoelectric voltage (dE) across the external load resistance from which Equation (1) is $a_{1,2}dT$ (where $a_{1,2}=a_1+a_2$). The power absorbed in the closed circuit is thus $-a_{1,2}dT\,dI$ where the negative sign indicates power taken from

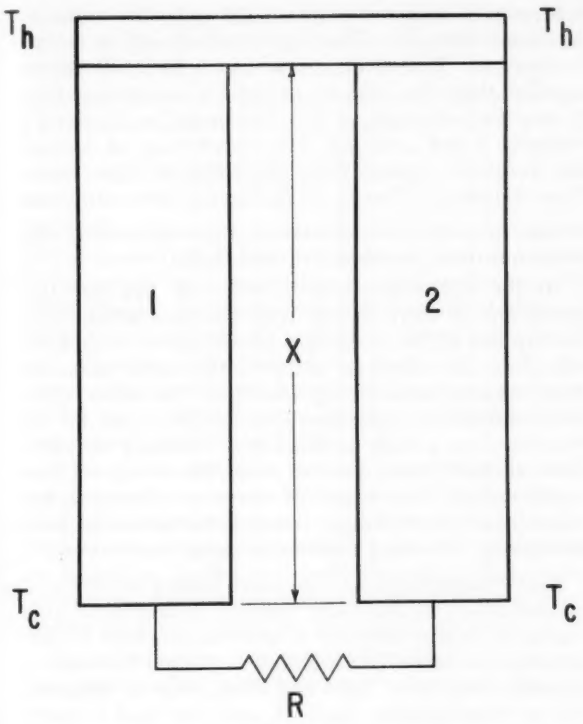


Figure 1.

the circuit. The thermoelectric potential generated in the circuit, and the current resulting, will cause a Peltier effect at the junction. (We assume that the two conductors are joined by a resistanceless metallic bridge.) From Equation (2), the Peltier heat evolved at one junction will be $\Pi^*_{1,2}\,dI$, while the heat absorbed at the other junction will be $\Pi^*_{2,1}\,dI$. The total Peltier effect is then

$$\Pi^*_{2,1}\,dI - \Pi^*_{1,2}\,dI = d\Pi^*\,dI = \frac{\partial\,\Pi^*}{\partial\,T}\,dT\,dI.$$

The Thomson effect, from Equation (3), may be developed similarly as $(\tau_1-\tau_2)dT\,dI$. One can now write:

$$(\tau_1-\tau_2)\,dT\,dI + \frac{d\,\Pi^*}{dT}dI - a_{1,2}\,dT\,dI = 0$$

or

$$(\tau_1-\tau_2) + \frac{d\,\Pi^*}{dT} = a_{1,2}\ \text{volts/°K} \quad \ldots\ldots (4)$$

Note that the Peltier effect and the Thomson effect are reversible, if either the current dI or the temperature difference dT changes sign, while the power loss is irreversible. If we consider the reversible effects separately, another relationship can be developed which can be, and has been, checked experimentally and which may be regarded as some confirmation of the basic underlying assumption (that of the separability of the processes). Remembering the second law of thermodynamics, reversibility of a process requires that there be no change of entropy, or, stated in the form of an equation $\sum\frac{Q}{T}=S=0$. Applying this to the thermoelectric processes in Figure 1, the hot junction receives an amount of Peltier heat $\Pi^*_h\,I$ and the cold junction gives up an amount of heat $\Pi^*_c\,I$. (It should be noted at this point that Π^* is dependent on the temperature.) At the same time, in each conductor, Thomson heat is generated, the effect of which is $(\tau_1-\tau_2)\,I\,dT$. We write the zero change of entropy as:

$$\frac{\Pi^*_h}{T_h}\,I - \frac{\Pi^*_c}{T_c}\,I + I\int_T^{T_h}\frac{\tau_1-\tau_2}{T}\,dT = 0$$

Eliminating I from the equation and differentiating with respect to T, one obtains:

$$d\frac{\frac{\Pi^*}{T}}{dT} + \frac{\tau_1-\tau_2}{T} = 0 \quad \ldots\ldots (5)$$

Remembering that the value of Π^* is dependent on temperature:

$$d\frac{\Pi^*}{T} = \frac{T\,d\,\Pi^* - \Pi^*\,dT}{T^2} = \frac{dT\left(T\frac{d\Pi^*}{dT} - \Pi^*\right)}{T^2}$$

and

$$\frac{d\frac{\Pi^*}{T}}{dT} = \frac{T\frac{d\Pi^*}{dT} - \Pi^*}{T^2} \quad \ldots\ldots (6)$$

Substituting Equation (6) in Equation (5) results in:

$$\frac{d\Pi^*}{dT} = \frac{\Pi^*}{T} = -(\tau_1-\tau_2) \quad \ldots\ldots (7)$$

Remembering from Equation (4) that $\tau_1-\tau_2=a_{1,2}-\frac{d\Pi^*}{dT}$, Equation (7) may be rewritten as:

$$a_{1,2} = \frac{\Pi^*}{T} \quad \ldots\ldots (8)$$

Each of the quantities in Equation (8) has been separately measured, and experiment has always confirmed the equation. Equation (8) is known as the First Kelvin Relation.

If Equation (8) is differentiated with respect to T, the following relationship is developed:

$$\frac{da}{dT} = \frac{d\,\frac{\Pi^*}{T}}{dT} = \frac{\tau_1-\tau_2}{T}\ \text{volt/°K} \quad \ldots\ldots (9)$$

Equation (9) is known as the Second Kelvin Relation.

Before going further, it will be necessary to delve somewhat into the atomic structure of materials in order to gain some understanding of what actually

happens and to some extent why it happens. For the purposes of this paper, materials can be divided into three groups: (1) insulators, (2) semiconductors, and (3) conductors. Semiconductors, which are of the greatest use for thermoelements, are generally characterized by the fact that their electrical conductivity is increased by a rise of temperature and may also be increased by the presence of certain impurities in solid solution with them. To understand the use of semiconductor materials for thermoelectric power, one must first consider the behavior of their electrons and what has been termed "holes" in the material.

Basic to the theory of semiconductors is the fact that electrons can act as charge carriers in two distinguishable and distinctly different ways: by movement of electrons in excess of those attached to the atoms, and by movement of holes (which involves transfer of electrons from atom to atom). The quantum mechanical explanation of these two processes in terms of "energy bands" and "Brillouin zones" is a well-developed theory of atomic physics, but it is also well beyond the scope of this paper to explain in other than the briefest detail necessary for understanding.

In classical mechanical treatments of conductivity, the current carriers are thought of as small particles moving in random thermal motions on which are superimposed the effect of electric and magnetic fields. Except for their smallness, the particles are imagined to have much the same attributes as larger solid bodies, such as are encountered in ordinary experience, golf balls for example. However, these theories have failed to account for many aspects of the behavior of electrons where quantum mechanics (which includes wave mechanics) have succeeded. Quantum mechanics brings with it a different set of concepts, which include the "wave function," "probability density," "energy level," "quantum state," and "Heisenberg's Uncertainty Principle"—concepts which are based on the development of the mathematical postulates of the theory. In general, a mastery of this mathematical machinery is achieved only in a postgraduate course in physics. Fortunately, the results of the application of quantum mechanics to the motions of electrons in crystals do not need to be described in terms of mathematical machinery itself, but can be presented, instead, largely in word pictorial terms.

However, since it will be necessary to involve the use of wave mechanical terms in equations which must be resorted to for explanation, a brief foray into wave mechanics will be presented next.

In 1927, it was first discovered that diffraction patterns could be observed and recorded photographically when beams of electrons were reflected from crystals. This remarkable discovery showed that electrons possessed the properties of waves as well as particles and a beam of electrons of velocity u was found to behave as though it were associated with waves, of wave length λ, given by the relation $\lambda=h/p$ where h is Planck's constant and p is the momentum. For electrons whose velocity is much smaller than the velocity of light c, the momentum p may be put equal to the "rest mass" m times the velocity u and $\lambda=h/mu$. This is not true, of course, for velocities approaching the speed of light, since from Einstein's Theory of Relativity, dynamic mass $=\text{rest mass}/\sqrt{1-u^2/c^2}$ and at high velocities, the dynamic mass increases substantially.

In the diffraction experiment, one can use the equations of wave theory with the assumption that the square of the amplitude of the waves is proportional to the electron density—the dark areas of high intensity are the regions where the wave equations indicate a high intensity, and this can be interpreted as a high probability of finding an electron at that place. In this way, the whole of the mathematical framework of the wave theory is retained, but we no longer imagine the existence of a stationary vibrating medium causing the waves.

The interpretation of the wave theory in terms of probabilities implies that there is a degree of uncertainty in the behavior of a single electron. If, for example, a beam of electrons is passed through a crystal, a series of light and dark rings is obtained on the photographic plate. If, now, we pass a single electron through the crystal, we cannot predict where the electron will travel. All we can say is that there are different probabilities of its traveling in different directions, these probabilities being greatest in the directions corresponding to the rings of greatest intensity. The use of wave equations with a probability interpretation does not enable us to "understand what is happening," but it places us in a position in which we can describe and predict experimental results in terms of the appropriate probabilities and can include both the wave and particle aspects in one theory.

We know from experiments that an electron is accelerated or retarded by an electric field with a corresponding change in the momentum mu. From the relation $\lambda=h/mu$, it follows that the wave length associated with an electron is inversely proportional to its velocity. We have thus a condition of affairs in which, if an electron moves through a field of varying potential, the associated wave length is continually changing. If the changes of potential are appreciable over distances of the order of the associated wave length of the electron, some completely new phenomena are met with which cannot be explained by classical mechanics. The wave length associated with electrons in atoms are of the same order as the "sizes" of the atoms, or of the distance between atoms of a metallic lattice. Under these conditions, the wave-like characteristic of the electrons produce many effects. Some of these effects are responsible for properties of the material and can only be understood in terms of

wave mechanics. A thorough understanding of the behavior of electrons in metals requires some understanding of wave mechanics.

It can be shown that the velocity U of these hypothetical electron waves is given by:

$$U=\frac{mc^2+\frac{1}{2}mu^2+W}{mu}$$

In most ordinary problems, the term mc^2 is so much the greatest that U is of the order of c^2/u and since u can never be greater than c, this implies that U must always be greater than the speed of light c. Thus the wave velocity is not the actual velocity of the electron. This serves to emphasize that the waves are merely mathematical functions and are not of any material nature because nothing material can travel faster than light.

A beam of electrons of uniform velocity u will correspond to a monochromatic ray of the hypothetical mechanical waves of velocity U. The hypothetical "something which forms waves" is denoted by ψ and in accordance with general analogy, the amplitude of the hypothetical ψ waves is a measure of the electron density at the place concerned.

The electron motion is thus described by a wave equation similar to Schroedinger's first equation:

$$\frac{h^2}{8\Pi^2 m}(\nabla^2\psi)+(E-W)\psi=0 \quad \ldots\ldots\ldots\ldots (10)$$

where

h = Planck's constant, erg-sec
m = mass, gram

$$\nabla^2\psi=\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2} \text{ cm}^{-2}$$

E = total energy of electron, ev
W = potential energy of electron, ev
ψ = a complex wave function

The wave length λ is given by $\lambda=h/mu$. The wave length λ is related to the wave number k_w by $k_w=2\Pi/\lambda=2\Pi\, mu/h$. Having both magnitude and direction, k_w is treated as a vector quantity in "k space" which can have dimensions parallel to real space. The wave number is important in explanations to follow.

If an electron is to act as a charge carrier, it must be free to move, that is, it must be excess to the valence electrons attached to the atoms. Thus, it will be referred to as a free-electron, and a free-electron theory has been developed. In the free-electron theory, the structure of the solid is ignored, and the material is regarded as containing a number of electrons which move about freely as though they constituted the particles of an electron gas. The forces between the electrons are ignored. In the free-electron theory, the kinetic energy of an electron ε and its wave number k_w are related by the simple equation:

$$\varepsilon=\frac{h^2 k_w^2}{8\Pi^2 m} \text{ electron volts} \quad \ldots\ldots\ldots\ldots (11)$$

However, one cannot be exact if the forces exerted on each electron by the others is ignored, The effect of a periodic field is to complicate the relationship between ε and k_w. If we make the simplifying assumption that in considering the motion of any one electron the remaining electrons may be regarded as smoothed out throughout the crystal, the one electron under consideration can be pictured as moving through a strictly periodic field. Subject to this assumption, and resorting to wave mechanics, Equation (11) turns out to have the form:

$$\psi=e^{i(k_w r)}\phi_k(x, y, z) \quad \ldots\ldots\ldots\ldots\ldots (12)$$

where $\phi_k(x, y, z)$ is a function which depends in general on k and has the three-fold periodicity of the lattice.

Equation (12) then represents a plane wave of wave length $2\Pi/k_w$, but with the wave modulated in the rhythm of the lattice. A mathematical examination of the equation shows that there are only certain values of the energy (eigenvalues) for which k_w is real and that for other values of the energy k_w is imaginary and, therefore, forbidden, i.e., those values of energy for which k_w is imaginary do not exist. From this, it is concluded that if one considers electron energy states corresponding with any one plane of the vector k_w, the energies will not be a continuous function of the wave numbers, but will show gaps of forbidden energy.

Consider now a hypothetical one-dimensional material in which the potential energy of the electron undergoes a regular periodic variation. A plot of the energy ε versus the wave number vector k_w would have the relationship shown in Figure 2 where the portions between a_1b_1, a_2b_2, etc., are forbidden ranges of energy. These forbidden ranges of energy are explainable by the Brillouin zone theory. Briefly, as an electron travels, its wave length changes until it reaches a condition where it undergoes a "Bragg reflection" within the crystal. A Bragg reflection is similar to that of reflected light where the component of the velocity of the energy wave parallel to the reflecting plane is not changed, but the component of the velocity perpendicular to the reflecting plane is reversed. The effect of an applied electric field to an electron in a given energy range, say b_1a_2 of Figure 2, is to make it pass through a series of energy states until its wave number reaches the value of k_w represented by point a_2. At this point, an abrupt change in the wave number occurs. The electron does not pass into the energy zone at b_2 even if the energy gap is quite small, say on the order of one electron volt. It is emphasized that Bragg reflections are quite distinct from the interactions (collisions) of electrons with the thermal lattice vibrations. In fact,

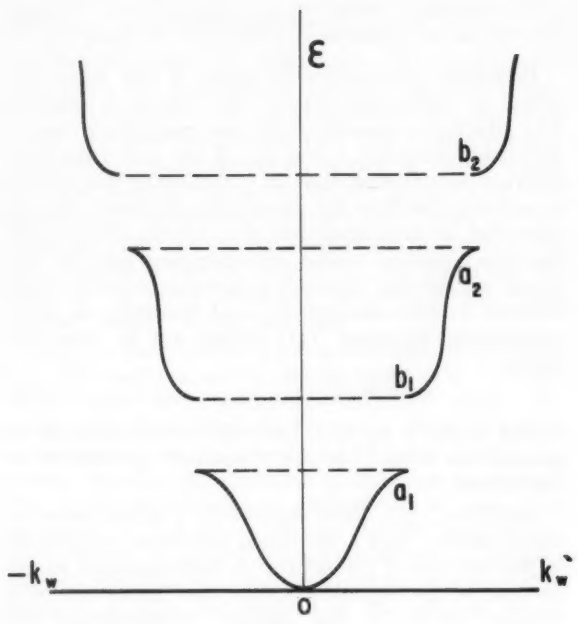


Figure 2.

Bragg reflections take place even at absolute zero in the complete absence of thermal vibrations.

From the above, it may be appreciated that because of Bragg reflections, if there is a forbidden energy gap between the zones (actual energy gaps vary in size and zones can even overlap with no gap at all in some solid solutions), an electric field alone will not enable an electron to pass from a state in one zone to a state in another. As a matter of fact, thermal energy of atomic lattice vibrations is required.

If one plots the number of electrons within an energy band of a pure material at each energy value, the result is a curve, such as Figure 3. In this case, Zone 1 is filled. All the quantum states for electrons in Zone 1 are fully occupied, and an energy gap separates the fully occupied zone from the next one as illustrated in Figure 3. This substance would be an insulator at absolute zero temperature and perhaps at ordinary temperatures. However, if at higher temperatures the electrons were thermally excited, by interactions with thermal vibrations of the atoms, sufficiently to jump from the lower energy zone to the higher one, the substance would be classed as an intrinsic semiconductor. In its new state in the higher zone, the electron would be separated from its atom and would act as a free electron, giving rise to a conductivity which would increase with the temperature as a greater number of electrons was excited into the second zone. This is characteristic of a semiconductor as was mentioned previously.

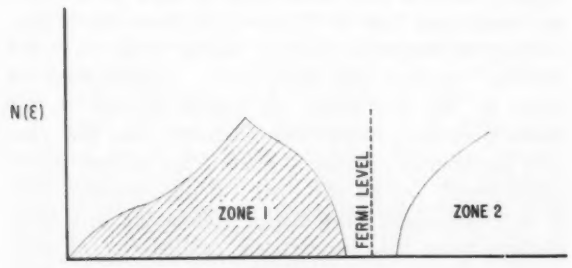


Figure 3.

It is important to note that it is the thermal lattice vibrations which excite the electrons from one zone to another and not the effects of an electric field. Intrinsic semiconductors are relatively rare. Graphite, silicon, and germanium are intrinsic semiconductors.

A second class of semiconductors owes its properties to the presence of impurity atoms in its lattice and is represented schematically in Figure 4.

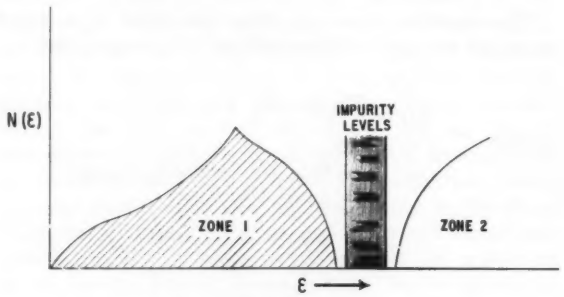


Figure 4.

Here a completely filled zone (marked 1, but not necessarily the lowest energy zone or band) and the empty zone above it are separated by a comparatively narrow energy gap. The effect of adding impurity atoms is, in general, to create new energy levels, and it may happen (or is designed to happen) that these be within the energy gap. At absolute zero temperature, the substance will be an insulator, but as the temperature is raised, one or both of two processes may occur.

Electrons may be excited thermally from the impurity energy levels into the conduction Zone 2. These electrons then enter states where they will act as free electrons, that is, they are outside of the forces holding them in the vicinity of the parent nucleus. Now, if a rectangular-shaped conductor of this type of material has a current passed through it between the ends of the material in the presence of a transverse magnetic field, a difference of potential will be generated between the sides of the

conductor. This is known as the Hall effect. By convention, the Hall coefficient is negative if the potential is raised on that side of the material on which the current generating the magnetic field has the opposite direction from the current in the material. Figure 5 illustrates the Hall effect for conduction by excess electrons as in the material under consideration. In this case, the semiconductor is known as "N"-type because the electrons act as though they had a normal negative charge. The impurity atoms are called "donor" atoms because they give electrons to the second zone. If the gap between Zones 1 and 2 is sufficiently narrow, the substance may exhibit both intrinsic and N-type semiconductivity, the N-type predominating at low temperatures and the intrinsic-type at high temperatures.

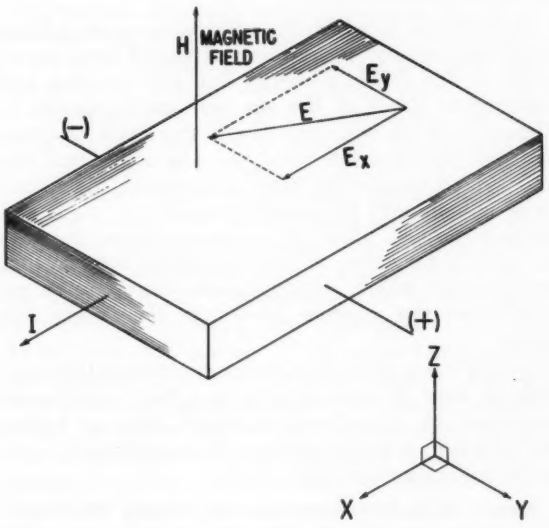


Figure 5.

The other process which may occur with impurity atoms present is that electrons may be excited thermally from the top of Zone 1 into the impurity energy levels whose atoms are then called acceptor atoms. This process leaves some of the states at the top of Zone 1 unoccupied so that the application of an electric field can cause an electron movement in Zone 1 and so create a conductivity. From the Brillouin zone theory, in a partially filled zone under the influence of an electric field, the rate of change of the wave velocity is given by:

$$\frac{dv}{dt} = \left(\frac{d^2\varepsilon}{d\,k_w{}^2}\right)\left(\frac{4\,\Pi^2}{h^2}\right) e\,F \text{ cm/sec}^2 \quad \ldots\ldots\ldots (13)$$

where e = the electron charge
F = force field

According to classical mechanics, the expression for the acceleration of an electron under an electric field is:

$$\frac{dv}{dt} = \frac{e\,F}{m} \text{ cm/sec}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

A comparison of Equations (13) and (14) shows that wave mechanics replaces the mass m of the electron in classical mechanics by $h^2/4\Pi^2 \dfrac{d\,k_w{}^2}{d^2\varepsilon}$. This quantity is called the "effective mass." An examination of the terms for effective mass shows that if $\dfrac{d^2\varepsilon}{dk_w{}^2}$ is negative, then the acceleration of the electron is also negative. An examination of Figure 3 shows that the curves at the top of each energy zone have a horizontal slope where $\dfrac{d\,\varepsilon}{d\,k_w}$ approaches zero and $\dfrac{d^2\varepsilon}{dk_w{}^2}$ becomes negative. Thus, the effect of an electric field on electrons of states at the top of each zone is to decrease the velocity, and the effect is as though the electron had negative mass or a positive charge. Materials which exhibit this process are called P-type semiconductors, and the sign of the Hall effect is abnormal (i.e., positive) as shown in Figure 6. The Hall effect is commonly used to identify materials as N- or P-type. At this point, it may be well to say a little more about P-type semiconductors and the behavior of the electron acting as if it had a positive charge. Electrons acting in this manner are called holes since they are the result of an electron entering a level outside of its

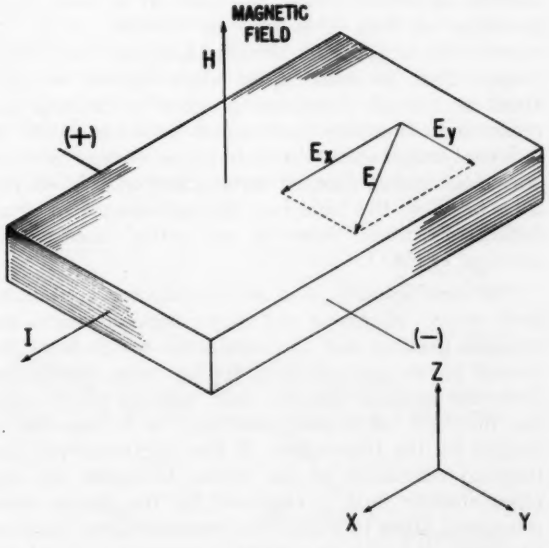


Figure 6.

normal energy zone and leaving an over-all positive charge and unoccupied state (hole) in its place.

Consider silicon containing arsenic, an N-type semiconductor. The free arsenic atom has five valence electrons surrounding its nucleus. If each arsenic atom in the solid solution displaces a silicon atom from its regular site in the normal silicon lattice, it will use only four of its five outer shell valence electrons in forming four covalent bonds with the four neighboring silicon atoms. The fifth electron is excess. The arsenic atom without its fifth electron is electrically positive and is an immobile localized positive charge which, as long as the fifth electron remains in the vicinity, is canceled by the electron charge and it does not disturb the over-all electrical neutrality of the crystal. The excess electron is weakly attracted to the immobile positive arsenic atom and at low temperature is bound to it. However, at room temperature, the thermal vibrations of the atom shakes it off (really excites it to an energy level where it is in a new zone), and it becomes free to move under the influence of the electric field.

The P-type process may be described by considering silicon containing boron impurity atoms. In this case, the impurity atom has only three valence electrons in its outer shell. When it displaces a silicon atom from its regular site in the lattice, it cannot complete the valence bond structure surrounding it. Thermal agitation of the lattice atoms, however, can excite an electron in an adjacent bond enough to move into the vacant valence hole, leaving, however, a vacant state in the zone of the atom it left and making the boron atom an immobile localized negative charge. For the sake of convenience, the picture can be described as a negative boron atom attracting a positive hole, but that thermal agitation shakes the hole off at room temperature so that it is free to wander about. Of course, this is not what actually happens, but, if one forgets that an unoccupied state cannot wander about as though it were a physical something but remembers that the unoccupied state can occur in different areas due to a state in an energy zone of one atom being vacated as another atom's energy zone is filled, the hole has the appearance of wandering. Further, there is an actual measurable physical effect.

The conductivity of a semiconductor containing both excess electrons and holes depends upon the number present and the ease with which they are moved by an applied field. As has been shown before, the applied electric field has no effect upon the numbers of excess electrons or holes—this is caused by the interaction of the electrons with the thermal vibrations of the atoms. However, the applied electric field is required for the excess electrons and holes to make the semiconductor conductive since it keeps the electron movement (and the hole movement) from being completely random with no resultant current flow. Thus, the conductivity depends upon the temperature as one factor.

A large Seebeck voltage requires a large change of entropy of the electrons with temperature. Entropy basically is an expression of the amount of freedom which in turn, if we use the mental picture of a free electron cloud moving around fixed atoms, will be dependent on the number of free electrons as one factor. The movement of the free electrons may be impeded if the density of electrons in the conduction energy zone is too great. This is the case with metals. If the density of free electrons per cm^3 in on the order of 10^{23} per cm^3, the system is said to be metallic or degenerate. The increased movement of electrons which can be induced by temperature change is small. The optimum filling of the conduction energy zone has been determined by experiment to be about 10^{19} carriers per cm^3 at which the carriers are still mobile.

The amount to which the conduction zone is filled is determined by the position of the "Fermi level" which is the dividing energy line for occupied and unoccupied states of the electron and is shown in Figure 3. In an insulator, the Fermi level is about halfway between the filled valence zones and the unoccupied conduction zone. In a metal, the Fermi level is well into the conduction energy zone and likely to be well filled. In a semiconductor, the Fermi level is very near to the conduction zone so that temperature effects easily enable electrons to escape from the valence zone into the conduction zone.

It may be well at this point to attempt the most difficult task of summarizing in a few well-chosen sentences what has been developed thus far before the number of things presented in explanation obscure the important basic facts.

First, the three thermoelectric effects were presented. A temperature difference between the ends of two different semiconductors produces a thermoelectric voltage. A current through the junction of these two semiconductors will generate or absorb heat at the junction, and this same current will generate or absorb heat in each of the two conductors in the presence of the temperature difference. Next, the relationships between the coefficients used in calculating these effects were developed. Then, the theory of semiconductors was examined because semiconductors are basic thermoelectric materials. It was shown that the electrons in the shell of an atom have energies which lie in discrete zones. In order for an electron to participate in electrical conductivity, it must be freed from its normal energy zone by the effects of excitation from thermal lattice vibrations and made to drift in a given direction by application of an electrical field. It was shown how intrinsic semiconductors can change from insulators at absolute zero temperature to semiconductors at higher temperatures when the

thermal vibrations of the atoms jump electrons into the conduction energy zone. It was also shown how the addition of impurity atoms of the proper energy zone could make conduction possible in a semiconductor either by excess electrons, by holes (electrons which act as if they have positive charge and negative mass), or by both. The Hall effect, by which a semiconductor material can be shown as N-type with excess electrons or P-type with holes, was briefly described, and a somewhat wordy picture of electron and hole movement was presented.

Thus far, we have covered the change of conductivity in a semiconductor material by temperature changes and have tried to present part of four or five advanced textbooks of atomic physics theory, quantum mechanical theory, and excess electron and hole theory in a few paragraphs. Then, these few paragraphs were further compressed into a one-paragraph summary of progress thus far. If an understanding of thermoelectric power looks complicated and difficult to you, be assured that you are not alone in your reaction. For years, people earned degrees in electrical engineering without having the slightest idea of what an electrical current really was. Even now we do not know what nuclear forces really are. But the more we learn, the more complicated become our attempts to describe basic physical phenomenon in mathematical terms which will in one theory account for everything that we know is happening and at the same time tell us how it might have happened.

At any rate, the reader, if I have been successful in condensing the correct parts of volumes of theory into a few paragraphs which still enable understanding, should be aware that a temperature gradient in a semiconductor will produce more "free" electrons (or more holes) at the hot end than the cold end and should have some idea of what excess electrons and holes really are. If a P-type semiconductor is joined with an N-type semiconductor, we know that in the presence of a temperature gradient between the ends, thermoelectric effects appear. We should now examine a P-N junction.

Although it is difficult if not impossible to attain in practice, assume that a perfect junction has been made—as if a single piece of semiconductor material had a variable concentration of impurities, changing gradually from donor to acceptor atoms, in such a manner that the transition from N- to P-type occurs without an increase in resistance at the joint. Figure 7 shows such a junction. Part (a) of Figure 7 shows pictorially the distribution of donors, acceptors, holes and electrons at room temperature; (b) shows the densities of donors and acceptors; and (c) shows the densities of holes and excess electrons. These densities adjust themselves under the constant temperature condition represented so that there is no current either of holes or electrons and so that the recombination of holes and electrons in any small volume element just balances

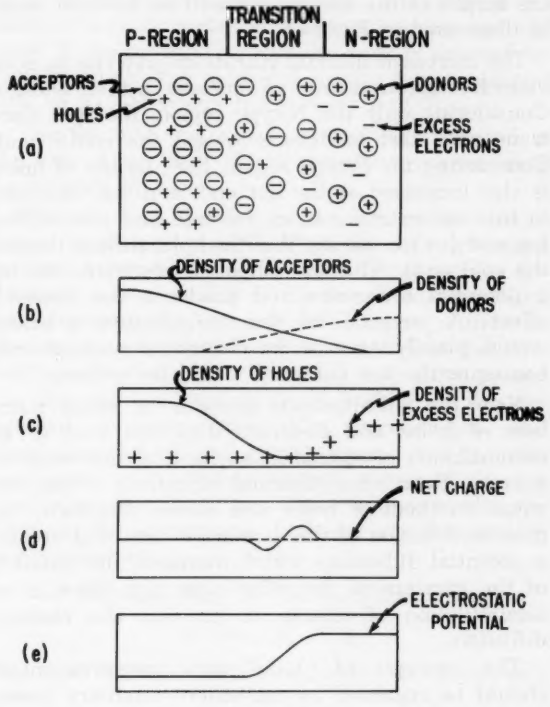


Figure 7.

the thermal rate of production of holes and excess electrons. Since the holes are more concentrated in the P-type region, they tend to diffuse to the N-type region. This tendency is opposed by an electrostatic field of the charged but immobile impurity atoms. In Part (d), the net charge density is shown (net charge density = e [holes − excess electrons + donors − acceptors] where each factor is given its positive or negative charge sign).

If, by some means, the temperature of the transition region (or the butted ends of the P- and N-type zones) is raised above room temperature while the other ends are held at room temperature, additional holes and excess electrons will be formed and

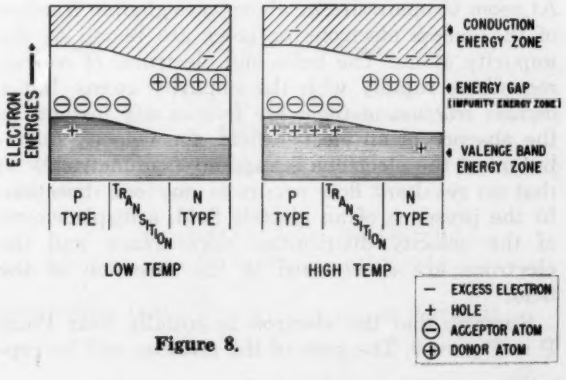


Figure 8.

the height of the energy hill will be lowered some as illustrated in Figure 8.

The increased thermal vibrations give rise to both more free electrons and an increase in their energy. Considering only the N-type region, the free electrons will start to diffuse toward the cooler end. Considering the P-type region, the number of holes is also increased at the hot end, and the electrons in this region move from the cold end toward the hot end (or we can say that the holes diffuse toward the cold end). This movement of electrons sets up a potential difference and produces the Seebeck effect. A reversal of the temperature gradient would, plainly, reverse the electron movement and, consequently, the potential would be reversed.

Now the simultaneous transfer of equal numbers of holes and electrons does not lead to an accumulation of charge in any end of the semiconductors. Even when thermal vibrations create unequal numbers of holes and excess electrons, the greater diffusion of the carriers of one sign creates a potential difference which increases the mobility of the carriers of the other sign and there is no accumulation of charge to prevent the electron diffusion.

The concepts of "hole" and "negative mass" should be regarded as convenient auxiliary means of simplifying complicated statistical calculations of the behavior of a large number of electrons in a periodic lattice field. The movement of positive holes does not mean that there are free positive charges in the semiconductor. But all departures from periodicity, due either to the thermal agitation of atoms, geometrical defects, or extraneous impurities, affect the uniform, and on the average, rectilinear motion of a free electron in a crystal. All such imperfections introduce a certain probability of deviation of the electron path away from the direction the electron has before it meets the distortion of the periodicity. Therefore, distortions are found to act as electron scattering centers and have an effect on the value of the thermoelectric emf.

Suppose, now, that the semiconductor junction of Figure 7 is returned to an isothermal state and then an electric potential is imposed across the ends. At room temperature or above, a negligible fraction of the excess electrons or holes are bound to the impurity atoms. The holes and electrons, of course, recombine rapidly with the impurity atoms, but a certain fraction of them are free at any instant. In the absence of an electric field, the velocity distribution of the electrons is random (symmetrical) so that no resultant flow occurs in any one direction. In the presence of an electric field, a displacement of the velocity distribution takes place, and the electrons are accelerated in the direction of the field.

Suppose that the electron is initially near Point P in Figure 9. The path of the electron will be represented by the shaded parts. Heisenberg's principle of uncertainty states that both the velocity and the position of the electron cannot be known with certainty. Thus, the shaded portion represents uncertainty as to position. At the Point AB, the wave number k_w (related to velocity) has reached the critical value for a Bragg reflection, and it is reflected by interactions with the lattice plane atoms represented by the straight lines. The electron then sets out on a new curved trajectory which moves it in the general direction of the imposed field. Kinetic energy of motion of an electron carries it higher in the conduction band of Figure 8. Similar comments apply to the behavior of holes in an electric field except that the direction is reversed against the field, and the kinetic energy of motion of a hole carries it lower in the valence bond energy band. The generation, or absorption, of heat at the junction of two semiconductors, the Peltier effect, is thus due to the interaction of either electrons or holes with the atoms as they flow through the junction, generation of heat originating from the added excitation of the lattice atoms due to interaction with the higher energy electron, and the absorption of heat due to interactions with the lower energy holes.

Figure 9.

It now remains to attempt a logical sounding explanation for the Thomson effect—the generation or absorption of heat in a single semiconductor when a current flows through it and a temperature gradient exists between its ends.

In an electronic conductor, the withdrawal of a few electrons produces a local positive charge at the point of withdrawal. This positive charge produces an electric field which progresses with the speed of light (and has nothing to do with the speed of the carriers) and exerts a force on adjacent electrons so that they move in to neutralize the space charge. The net result is that the electrons in all parts of the conductor start to drift practically instantaneously. They flow into the conductor at the negative terminal and out at the positive terminal, and no

appreciable change in density of electrons occurs anywhere.

However, when a temperature gradient is imposed on a semiconductor, say N-type for an example, more excess electrons are freed at the hot end. The additional interaction of this increased number of electrons with the atoms of the conductor lead to an increase in the thermal vibrations at both the hot and the cold ends as the increased number of electrons join the original number of electrons drifting in the force of the electric field. With P-type semiconductor material, the effect is the reverse. The lower energy holes reduce the interaction and thus reduce the temperature of both ends.

It is thus seen that the change in the number of excess electrons and holes by changes in the temperature of a semiconductor and the different energy levels of the excess electrons and the holes account for all three of the thermoelectric effects—the Seebeck effect, the Peltier effect, and the Thomson effect. And, as shown previously, the relationship between the thermoelectric power, the Peltier coefficient, and the Thomson coefficient as related by:

$$\frac{d\Pi^*_{1,2}}{dT} + \tau_1 - \tau_2 = e_{1,2}$$

is only logical. Now we are ready to examine some of the principles which enable us to evaluate a thermoelectric generator.

Consider the thermoelement, Figure 10, consisting of a P-type and an N-type semiconductor joined by a resistanceless metallic bridge. An external resistance R is connected in the circuit across the cold ends. If the potential across the ends is denoted by E volts, the power delivered by the thermoelement will be $P=I^2R$ where the current $I=E/R$.

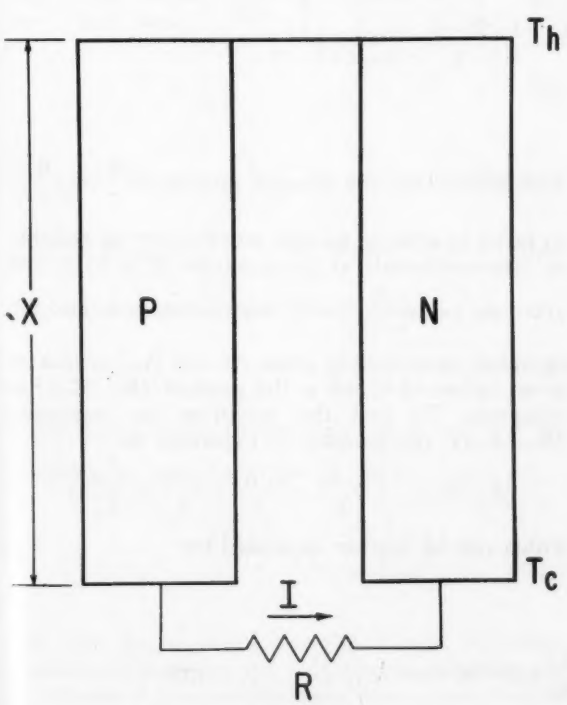


Figure 10.

The thermal emf, which in this case is equal to the sum of the thermal emf's of the two arms, may be denoted by $a_{PN}=|a_P|+|a_N|$.

The hot ends, joined by the bridge, are maintained at temperature T_h. The cold ends are maintained at temperature T_c, both temperatures expressed in degrees Kelvin. In developing equations which express the general performance of thermoelectric generators, it must be noted that the Seebeck coefficient a, the electrical resistivity ρ, and the thermal conductivity k of both arms are dependent on temperature. For simplification, and since the error will not greatly exceed ± 5 per cent over exact calculations, average values of the appropriate parameters are assumed in formulas derived for the assumption of parameters independent of temperature.

From Equation (1) the thermoelectric voltage is:

$$E = a_{PN}(T_h - T_c)$$

The total resistance of the circuit $R_T=R+r_P+r_N$ and the current in the circuit $I=\frac{E}{R_T}$ may be expressed as:

$$I = \frac{E}{R_T} = \frac{a_{PN}(T_h - T_c)}{R+r_P+r_N} \text{amperes} \quad \ldots\ldots (15)$$

From Equation (2), the Peltier heat Q_P is expressed as:

$$Q_P = \Pi^*_h I$$

or remembering that by the first Kelvin relationship $\Pi^*=a\,T$

$$Q_P = a_{PN} I\, T_h$$

or substituting Equation (15) for I, the equation is:

$$Q_P = a_{PN}\left(\frac{a_{PN}(T_h - T_c)}{R+r_P+r_N}\right)(T_h)$$

or

$$Q_P = \frac{a^2_{PN}\, T_h (T_h - T_c)}{R+r_P+r_N} = \frac{a^2_{PN}\, T_h (T_h - T_c)}{\left(\frac{R}{r_P+r_N}+1\right)(r_P+r_N)}$$

or letting $\frac{R}{r_P+r_N} = m_R$ and $r = r_P+r_N$

$$Q_R = \frac{a^2_{PN}\, T_h (T_h - T_c)}{r(m_R+1)} \text{watts} \quad \ldots\ldots (16)$$

The power output is given by $P_o = I^2R$. Rewriting Equation (15) as:

$$I = \frac{a_{PN}(T_h - T_c)}{R+r_P+r_N} = \frac{a_{PN}(T_h - T_c)}{r(m_R+1)}$$

and noting that $\frac{R}{r_P+r_N} = \frac{R}{r} = m_R$ or $R = m_R r$

then

$$P_o = I^2R = \frac{a^2_{PN}(T_h-T_c)^2}{r^2(m_R+1)^2} m_R r - a^2_{PN}(T_h-T_c)^2 \frac{m_R}{r(m_R+1)^2} \text{watts} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

and

$$I^2 = \frac{a^2_{PN}(T_h-T_c)^2}{r^2(m_R+1)^2} r = a^2_{PN}(T_h-T_c)^2 \frac{1}{r(m_R+1)^2} \text{watts} \quad \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

For the time being, Thomson heat will be neglected, regarding it as small in comparison with other terms. Of the total Joule heat I^2r generated in the thermoelement, half passes to the hot junction, returning power $\frac{1}{2}I^2r$ and the rest is transferred to the cold junction.

The efficiency η (eta) is defined as the ratio of the useful electric power P_o to the energy consumed from the heat source.

$$\eta = \frac{P_o}{q_h} \quad \ldots\ldots\ldots\ldots\ldots\ldots (19)$$

The heat flux ϕ (phi) transferred from the hot junction to the cold junction is:

$$\phi = \frac{K_N A_N (T_h-T_c)}{X} + \frac{k_P A_P (T_h-T_c)}{X}$$

or putting $\frac{k_N A_N}{X} = K_N$ and $\frac{k_P A_P}{X} = K_P$

$$\phi = (T_h-T_c)(K_N+K_P) \text{ watts/cm}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

The energy consumed from the heat source consists of the Peltier heat Q_P and the heat transferred by conduction ϕ, from which it is necessary to deduct the energy $\frac{1}{2}I^2r$ returned to the heat source. Using Equation (19) for η, and substituting Equation (17) for P_o,

$$\eta = \frac{P_o}{q_h} = \frac{a^2_{NP}(T_h-T_c)^2 \frac{m_R}{r(m_R+1)^2}}{\frac{a^2_{NP}T_h(T_h-T_c)}{r(m_R+1)} + (K_N+K_P)(T_h-T_c) - \frac{1}{2}a^2_{PN}(T_h-T_c)^2 \frac{1}{r(m_R+1)^2}}$$

or

$$\eta = \left(\frac{T_h-T_c}{T_h}\right)\left(\frac{\frac{m_R}{m_R+1}}{1+\frac{(K_N+K_P)r}{a^2_{PN}}\frac{m_R+1}{T_h} - \frac{1}{2}\left(\frac{T_h-T_c}{T_h}\right)\left(\frac{1}{m_R+1}\right)}\right) \quad \ldots (21)$$

Thus, the efficiency of the thermoelement is fully determined by: (a) the hot and cold junction temperatures, (b) the quantity $\frac{(K_P+K_N)r}{a^2_{PN}}$ (where $K = \frac{kA}{X}$ and $r = r_P + r_N$) which depends on the thermal conductivity, electrical resistance, and thermoelectric power of the materials used in the thermoelement and which will be denoted by $\frac{1}{z}$, so that:

$$z = \frac{a^2_{PN}}{(K_P+K_N)r}$$

and, finally, (c) the selected ratio $m_R = \frac{R}{r} = \frac{R}{r_P+r_N}$.

In order to achieve as high an efficiency as possible in thermoelements at given values of a, k, ρ, and arbitrary ratio $\frac{R}{r_P+r_N} = m$, it is necessary to find the optimum cross-section areas A_P and A_N, so that at given values of k and ρ, the product $(K_P+K_N)r$ is minimum. To find the condition for minimum $(K_P+K_N)r$, the quantity is expanded to:

$$(K_P+K_N)r = \left(\frac{k_P A_P}{X} + \frac{k_N A_N}{X}\right)\left(\frac{\rho_P X}{A_P} + \frac{\rho_N X}{A_N}\right)$$

which can be further expanded to:

$$(K_P+K_N)r = k_P\rho_P + k_N\rho_N + k_P\rho_N\frac{A_P}{A_N} + k_{N\,P}\rho\frac{A_N}{A_P} \text{ volt}^2/^\circ\text{K}-\text{cm} \quad \ldots\ldots\ldots\ldots\ldots\ldots (22)$$

If Equation (22) is differentiated with respect to A_P/A_N and equated to zero, the resulting equation gives the minimum value of $(K_P+K_N)r$.

$$(K_P+K_N)r = k_P \rho_P + k_N \rho_N + k_P \rho_N \frac{A_P}{A_N} + k_N \rho_P \left(\frac{A_N}{A_P}\right)^{-1}$$

$$d[K_P+K_N)r] = k_P \rho_N \, d\left(\frac{A_P}{A_N}\right) - k_N \rho_P \left(\frac{A_P}{A_N}\right)^{-2} d\left(\frac{A_P}{A_N}\right)$$

and $$\frac{d[(K_P+K_N)r]}{d\left(\frac{A_P}{A_N}\right)} = k_P \rho_N - k_N \rho_P \left(\frac{A_N}{A_P}\right)^2 = 0$$

or $$k_P \rho_N = k_N \rho_P \left(\frac{A_N}{A_P}\right)^2$$

and $$\frac{k_N}{\rho_N}\frac{\rho_P}{k_P} = \left(\frac{A_P}{A_N}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (23)$$

At this value of A_P/A_N,

$$(K_P+K_N)r = k_P \rho_N + k_N \rho_N + k_P \rho_N \sqrt{\frac{k_N \rho_P}{\rho_N k_P}} + k_N \rho_P \sqrt{\frac{\rho_N k_P}{k_N \rho_P}}$$

or $$K_P+K_N)r = k_P \rho_P + k_N \rho_N + 2\sqrt{k_P \rho_N k_N \rho_P}$$

or $$(K_P+K_N)r = (\sqrt{k_P \rho_P} + \sqrt{k_N \rho_P})^2$$

and at the condition for maximum z for best efficiency:

$$z = \frac{a^2_{PN}}{(K\rho+K_N)r} = \frac{a^2_{PN}}{(\sqrt{k_P \rho_N} + \sqrt{k_N \rho_N})^2} \text{degree}^{-1} \quad (24)$$

To find the value of efficiency at maximum power, we note that the condition for maximum power to the load leads, in the case of a thermoelement as with other current sources, requires $R=r_P+r_N$ or $m_R=1$ and then:

$$\eta = \frac{1}{2} \frac{T_h - T_c}{T_h + \frac{2}{z} - \frac{1}{4}(T_h - T_c)} \quad \ldots\ldots\ldots (25)$$

The value for $m_R = \frac{R}{r_P+r_N}$ for maximum efficiency is found by putting $\frac{\partial \eta}{\partial m_R} = 0$. We find, after a rather long but straightforward differentiation, that:

$$m_{optimum} = \left(\frac{R}{r_P+r_N}\right)_{optimum} = \pm \sqrt{1 + \frac{1}{2} z (T_h+T_c)} \quad (26)$$

Substituting this optimum value of m into the expression for η, and making $M = \sqrt{1 + \frac{1}{2} z (T_h+T_c)}$:

$$\eta = \left(\frac{T_h - T_c}{T_h}\right)\left(\frac{M-1}{M+\frac{T_c}{T_h}}\right) \quad \ldots\ldots\ldots (27)$$

The first factor represents the Carnot efficiency. The second describes the reduction of this efficiency as a result of irreversible losses due to heat conduction and Joule heat entering into the expression for Z and is sometimes called the thermocouple efficiency. Examination of Equation (27) reveals that the material parameters enter into the efficiency only in the combination denoted by Z. This quantity is called the figure of merit. The greater M is in comparison with unity, i.e., the greater Z and T_h+T_c, the smaller is the reduction in efficiency due to irreversible losses. Therefore, an increase of the hot junction temperature T_h increases η not only by increasing the value of the Carnot efficiency $\frac{T_h - T_c}{T_h}$, but also because of the simultaneous increase of M at a given value of Z. In order to achieve the maximum efficiency, the product $Z(T_h+T_c)$ must be a maximum compatible with the Carnot efficiency term.

As I have mentioned previously, the efficiency of a thermoelectric engine, as with any heat engine, is composed of a Carnot efficiency term which is modified by a term representing irreversible losses. In order to fully appreciate the possibilities of thermoelectric conversion, one must be familiar with cascaded heat engines.

The most familiar cascaded heat engine is the multistage steam turbine in which each stage extracts work from the steam passed to it from the preceding stage. Now we take note that different thermoelectric materials have their most efficient performance at different temperatures. Thus, if, instead of using a single thermoelement across the temperature differential between T_h and T_c, a cascade of matched elements is used with each element operating in its most efficient temperature range, the thermal efficiency of the engine is larger than the average efficiency of the component stages. The physical basis for this fact is that the losses in the first stage which become converted into heat may be converted back into power in the later stages as heat flows successively from one stage to another.

Full advantage of the more optimum temperature for each cascaded element cannot be taken, however, because in cascading elements, it becomes impossible for each element to operate with the optimum value of electric current; however, there is an appreciable over-all improvement of efficiency in cascaded elements. For example, with stage efficiencies of 15 per cent, a thermoelectric engine with properly matched cascaded elements operating between room temperature and 1800°C could have an over-all efficiency as high as 25 per cent. As experience is gained in the design of power plants utilizing thermoelectric power and uses are made of waste heat, the over-all plant efficiency may be quite attractive.

I will attempt summary number two. After going faintly into excess electrons and hole theory, the P-N junction was examined. And by means of diagrams and words, the effects of increased temperature at the P-N junction with no increase at the other ends was described as due to the formation of excess electrons and holes in such a manner that there was a flux of both holes and electrons moving away from the hotter junction and resulting in a drift of electrons in the same direction in both the P- and N-type materials. The effect of an electric field on the movement of holes and electrons was shown to be due to the effect of the field in increasing the velocity component of the electrons and holes parallel to the direction of the field and curving the trajectory between Bragg reflections. The increased kinetic energy of the electrons carried them higher in the conduction bands, and the kinetic energy of the motion of the hole carries it lower in its valence band; the increased interactions thus result in increasing or decreasing the thermal vibrations—this was the Peltier effect. The Thomson effect was similarly explained as due to the increased number of electrons (or holes) formed in the material and effecting both the hot and cold ends equally as they joined the current flow.

We then proceeded to develop the equations for the efficiency η of a thermoelement in a form which demonstrated that the efficiency was dependent on: (a) the hot and cold junction temperatures, (b) the value of the figure of merit $Z=\frac{a^2_{PN}}{K_r}$ which is dependent on the thermal conductivity k, electrical resistivity ρ, and the Seebeck coefficient a, and (c) the selected ratio of external resistance to internal resistance $\frac{R}{r_N+r_P}=m_R$. It was shown that the optimum ratio of thermoelement cross sections A_P/A_N which results in a maximum value of Z and thus of η is expressed by $A_P/A_N=(k_N\ \rho_P/k_P\ \rho_N)^{1/2}$ and at condition of Z for best efficiency:

$$Z=\frac{a^2_{PN}}{(\sqrt{k_P\,\rho_P}\ +\ \sqrt{k_N\,\rho_N})^2}\text{degree}^{-1}$$

The value of the efficiency at maximum power was shown to be:

$$\eta_{max}=\frac{1}{2}\,\frac{T_h-T_c}{T_h+\frac{2}{Z}-\frac{1}{4}(T_h-T_c)}$$

and the optimum value of $m_R=\frac{R}{r_P+r_N}$ was shown to be when:

$$m_{optimum}=\sqrt{1+\frac{1}{2}Z(T_h-T_c)}=M$$

Thus, the efficiency η was shown to be expressed by:

$$\eta=\left(\frac{T_h-T_c}{T_h}\right)\left(\frac{M-1}{M+\frac{T_c}{T_h}}\right)$$

Figure 11 is a thermoelectric element conceived by Westinghouse Electric Company and published in the unclassified literature. It is a UO_2 stainless steel clad fuel element surrounded by a layer of alternate N-type—P-type materials in a vertical stack. This type of element would convert 5 per cent of the fission heat into electricity, and the remainder would go to an ordinary steam cycle.

Before leaving the subject of thermoelectric power, it would be well to mention its competitor, thermionic power. Thermionic conversion of heat

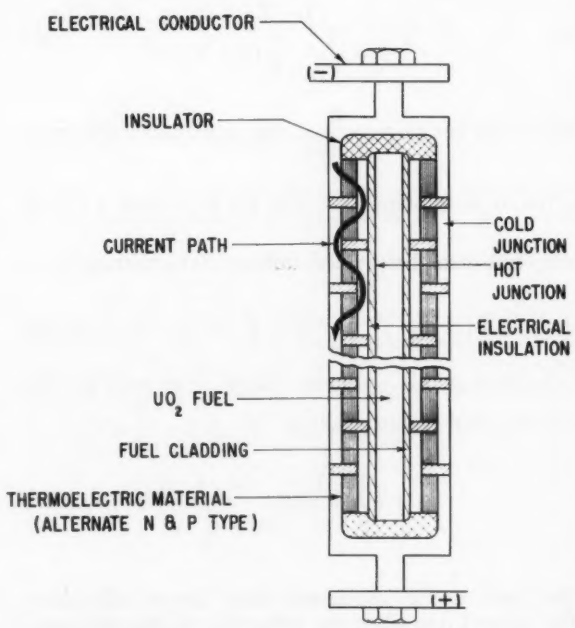


Figure 11.

directly into electricity is attracting attention because it promises to do so at higher efficiencies than thermoelements. But thermoelements are not out of the picture because thermionic converters require a heat source that can operate at quite high temperatures (T_h above 3000°F), whereas thermoelectric elements can operate quite well with T_h about 1800°F.

In its simplest form, a thermionic converter consists of two electrodes in a near vacuum. One electrode (the emitter) is kept hot enough to emit electrons thermionically while the other electrode (the collector) is kept cool. Electrons boiled off the emitter flow to the collector, out through the external load, and back to the emitter. This is analogous to the thermoelement in that the emitter is the hot junction, the collector the cold junction, and the near vacuum corresponds to the thermoelectric material between the junctions. Thermoelements have lower efficiencies for conversion primarily because of the scattering centers of the material itself which act as a thermal short circuit. The ideal thermoelectric material must have a high electrical conductivity and a low thermal conductivity. The thermal conductivity of the near vacuum between the two thermionic elements is practically zero. True, heat is transferred by radiation, but this is of less effect than the heat conducted in a thermoelectric solid. In addition, the vacuum space can be made an excellent electrical conductor if space charge effects can be overcome.

There are, so far, in the published literature several promising designs of thermionic converters. I will briefly mention one, the Los Alamos plasma thermocouple. This thermocouple operates in the core of a nuclear reactor and uses an incandescent uranium fuel element as the emitter and has the vacuum space filled with an ionized cesium gas at low pressure which serves to reduce the space charge. The emitter rod is made of a solid solution of ZrC:UC. The collector is stainless steel with copper cooling fins. Operated at a fuel pin temperature of 2000°C (3600°F) and a cesium pressure of about 10^{-5} mm Hg, an electrical conversion efficiency of about 5 per cent was attained. About 300-degree differential was maintained between the hot and cold ends.

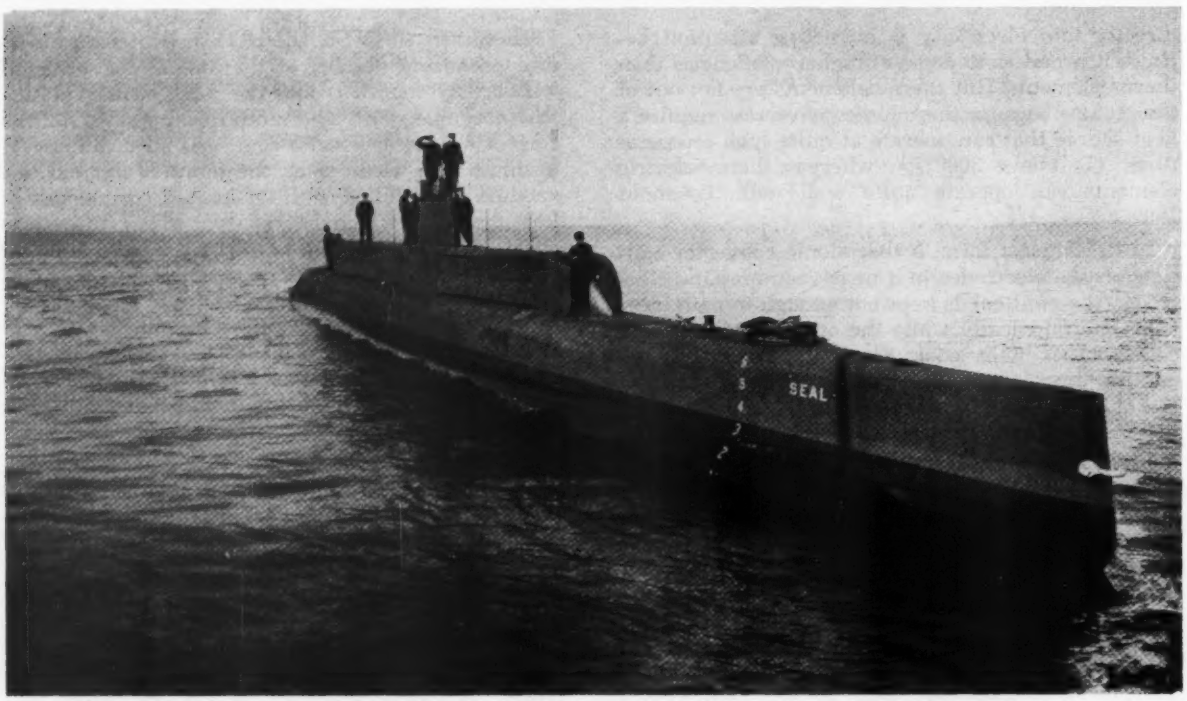
All of the material in this article can be gathered from numerous published sources and can be gathered by other would-be students of thermoelectric power from standard textbooks and literature. To thoroughly understand, the student should have a good course in atomic physics, theory of electrons and holes in semiconductors, thermodynamics, and, ahead of all, a knowledge of higher mathematics. The basic source of information on thermoelectric power is "Semiconductor Thermoelements and Thermoelectric Cooling," by A. F. Ioffe, Director of the Institute for Semiconductors of the U.S.S.R. Academy of Sciences. The technical journals concerned with physics, nuclear power, and electronics have recently been full of articles on thermionic conversion and contain excellent bibliographies.

SOVIET UNION WELDING GOALS

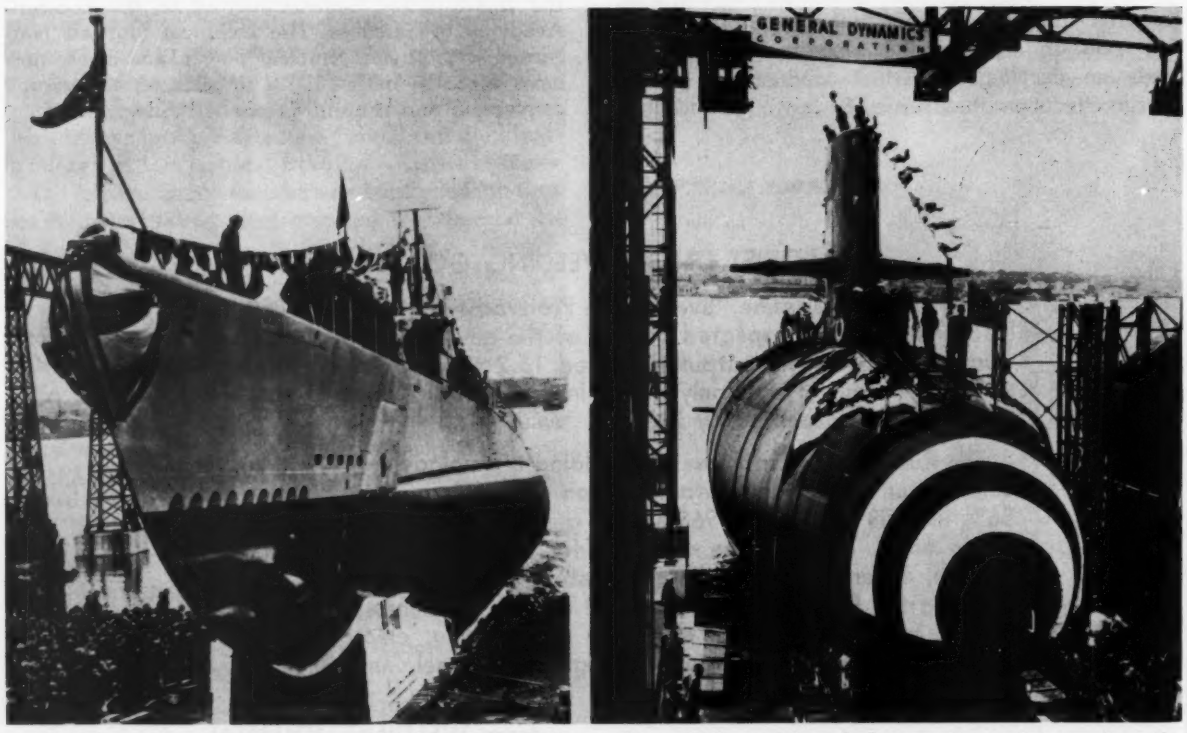
The Russian magazine "Svarachnoe Proizvodstvo" for May 1959 has a lead article on the expected growth of the gas welding and cutting industry in Russia. The output increased 16.2 times from 1940 to 1958, while the output of steel only tripled in this period. A further increase of 40 to 100% is expected by 1965.

The Russian plan for increase in welding technology from 1959 to 1965 calls for an increase in automatization of welding in shipbuilding from 56% in 1958 to 85% in 1965 and, in general, machine construction from 48 to 68%. To meet the demands for laboratory work to attain this growth, a centralized welding laboratory has been founded in Kaliningrad on the Baltic. Fields of interest will be mechanization of ship and tractor welding, inert-gas and CO_2 arc welding, electroslag welding, powder-core wire for depositing high-speed steel, and surfacing and metallizing techniques.

—from WELDING JOURNAL
January, 1960



The submarine *Seal*, Newport News Shipbuilding and Dry Dock Co. Hull 119, as completed in July of 1911.



Submarine style changes are exemplified in these undersea ships which were launched a quarter century apart at the Groton, Conn., shipyard of General Dynamics Corporation's Electric Boat Division. At left is the USS *Cuttlefish*, first sub built in Groton, shown going down the ways on November 21, 1933. The clipper-ship type bow of the *Cuttlefish* was conventional right through World War II and was necessary because diesel power made them only part-time submersibles. The streamlined atomic sub *Skipjack* is shown (right) at her launching in 1958. Nuclear power made the underwater ship a true submersible and led to adoption of many aerodynamic principles for submarines.

"ELECTRICAL ENGINEERING"

ADVANCES IN FUEL CELLS

ACKNOWLEDGMENT

This article, written by D. L. Douglas of the General Electric Research Laboratory, was published in the September 1959 issue of "Electrical Engineering."

FOR OVER 150 YEARS, the problem of converting the chemical energy of fuels directly into electric energy has challenged the best efforts of many electrochemists. The device for carrying out this conversion is called a fuel cell. In common with galvanic cells in general, a fuel cell consists of an anode at which oxidation takes place, an electrolyte, and a cathode at which an oxidizing agent is consumed. Fuels of interest are those conventionally used for the production of power and heat. Hydrogen must be added to the list for reasons which will become apparent later on. The only oxidizing agent of importance is molecular oxygen, either in pure form or in air.

Many excellent reviews of past fuel cell research and development have appeared in the literature.[1-5] This article is concerned with a review and appraisal of the more recent developments, particularly with regard to the possibility of generating central station power.

ENERGY CONVERSION

The conversion of the chemical energy of a fuel into electric energy by means of a heat cycle—as in a modern coal-burning power station, for example—suffers from an unavoidable limitation imposed by thermodynamics. This limitation applies to any process converting heat into work and derives from the nature of heat itself. When heat is converted into another form of energy, it must fall from an absolute temperature T_H to absolute temperature T_C, and the maximum fraction that can be converted under ideal conditions is $(T_H - T_C)/T_H$.

Let us see what this means in modern practice. Under good operating conditions, T_H *and* T_C will be near 1,050°F and 80°F, respectively—corresponding to a Carnot efficiency of 64 per cent. The overall efficiency of the power plant might be 40 per cent. That this efficiency approaches the Carnot so closely is an eloquent tribute to modern engineering. It is likely that further appreciable improvement will entail raising T_H, thus making greater demands upon construction materials. There is every reason to expect such improvements, but it will not come easily.

Conversion of the chemical energy of a fuel into electric energy by electrochemical means, as in a fuel cell, never involves the conversion of heat into work. The process is essentially isothermal and escapes the Carnot limitation. Actually, heat changes do occur in an operating fuel cell. These, while important in certain cases, are incidental to the primary conversion of the free chemical energy to electric energy. This possibility of avoiding the Carnot limitation constitutes the main reason for interest in fuel cells.

The thermodynamic principles are represented by the relationship

$$\Delta G=\Delta H-T\Delta S$$

where, for the net cell reaction, ΔG is the change in free energy, ΔH the enthalpy (heat content) change, and ΔS the entropy change. The maximum electrical work which can be obtained under reversible operation of the cell is equal to ΔG, the change in free chemical energy. For over-all engineering considerations, we are interested in the fraction of the total heat energy converted into electric energy. Clearly, the efficiency in the ideal case is

$$\eta_{id}=\frac{\Delta G}{\Delta H}=1-\frac{T\Delta S}{\Delta H}$$

The maximum possible efficiency then depends on the relative magnitude and sign of the waste heat or entropy term. Fortunately $\Delta S\approx 0$ for the important combustion reaction $C+O_2\rightarrow CO_2$. Thus, any fuel cell system which accomplishes this over-all reaction will have a high theoretical efficiency. No useful cell reactions with a positive entropy change, which would result in an ideal efficiency greater than one, are known.

Given an electrochemical system or cell reaction, the electrochemist is likely to be more interested in the efficiency on the basis of the free energy. This he will take to be the ratio of the operating cell voltage to the theoretical open-circuit voltage calculated from the relation

$$-\Delta G=nE^{\circ}F$$

where n is the number of electrons involved in the reaction, F is the Faraday constant, and E° the theoretical open-circuit voltage. A more precise measure of the free energy efficiency takes account of any losses from side reactions of the fuel as in the expression

$$\eta=\frac{E_{cell}\, i_{cell}}{-\Delta G\phi}$$

where E_{cell} and i_{cell} are the voltage and current being drawn and ϕ is a flow rate factor.

In the considerable literature on fuel cells, devices have been proposed for almost every conceivable fuel. The most attractive fuel cell would be one utilizing coal or the hydrocarbon liquids directly. Unfortunately, these fuels have very poor electrochemical properties. Inordinately high temperatures (1,000°C and above) are required to make carbon or coal ionize at an electrode. In addition, disposition of the impurities or ash normally present in coal is a formidable problem. Similarly, efforts to make saturated hydrocarbons react electrochemically, i.e., at an electrode, have met with little or no success.

Two fuels which have been found to be electrochemically active are hydrogen and carbon monoxide, the former being much more reactive than the latter. Because these fuel gases can be readily generated from coal and hydrocarbons, they are of interest for large-scale application in fuel cells. Some estimates of fuel costs, based on an assumed free energy efficiency of 70 per cent, vary from 3.6 mills per kwhr for producer gas fuel to 13.7 mills per kwhr for coal gas fuel and 14 mills per kwhr for hydrogen. These estimates are to be compared with the 3 mills per kwhr fuel cost of an average modern steam plant. However, the fuel cost story does not end here. Gorin has pointed out that the promise of the fuel cell can best be realized in integrating the cell and gasifier to utilize the waste heat from the cell to carry out the endothermic gasification reactions.[6,7] In a recent paper he shows that the fuel cost for power based on coal used in such an integrated plant (70 per cent efficient cell) will remain competitive with even the most optimistic estimates of future nuclear fuel costs.

Until fuel cells have been developed at least to the pilot stage, no reasonable estimate of the investment cost of the power produced can be made. However, both the gasifier and the cell units themselves are, in principle, much simpler devices than the boiler-turbine-generator complex of modern generating stations. The determining factor in the investment cost will be the life of the cells. If the life is sufficiently long, this cost may be well below that of present central power stations.

REACTION KINETICS IN FUEL CELLS

With one exception, all fuel cells under development today require for the generation of electricity the reaction of fuel and oxidant in gaseous form directly at their respective electrode surfaces. Only a little reflection is required to recognize some of the difficulties this requirement involves, since the reaction between gas, electrolyte, and electrode can take place only at the 3-phase boundary. While in theory this boundary is just a line—having but one dimension in space—in reality a finite reaction zone must exist. The problem was stated eloquently by William Grove in 1842 thus, "As the chemical or catalytic action in the experiment detailed in that paper [an earlier paper describing the first hydrogen-oxygen cell] could only be supposed to take place, with ordinary platina foil, at the line or watermark where the liquid, gas and platina met, the chief difficulty was to obtain anything like a notable surface of action."[8] Grove solved his problem by building 50 cells of platinum foil, after failing in attempts to make a spongy platinum. With the latter, he was on the right track and he knew it. In present-day fuel cells, the usual method of extending the area of the reaction zone is to fabricate the electrode as an electronically conducting porous structure which separates the gas (fuel or oxidant) and the electrolyte phases.

The design of the electrodes for long operating life at high current density is by far the most serious problem facing fuel-cell workers. Each electrode material, reactant gas, and electrolyte system is unique, involving particular methods of obtaining the required pore size distribution on a form consistent with fabrication in a usable form. Despite this uniqueness, some general requirements which must be met by any electrode can be listed:

1. High electrical conductivity.
2. Catalytic properties to increase reaction rates.
3. Stable pore size distribution to maintain electrolyte-gas interface at proper position within electrode over wide range of load currents and for long periods of time. In other words, the electrode must neither become "drowned" nor leak gas into the electrolyte.
4. Corrosion resistance.

It is instructive to consider the reaction at a gas electrode in more detail. The following steps in the mechanism may be proposed, more or less in order of occurrence:

1. Transport of gas molecules into pores.
2. Chemisorption of gas into electrode surface, involving dissociation into atoms in the case of hydrogen.
3. Transport of chemisorbed atoms or other species.
4. Reaction of chemisorbed species with ionic species in the electrolyte-electron transfer step.
5. Diffusion of ionic species in electrolyte to or away from electrode.
6. Transport of reaction product gas out of pores, countercurrent to flow of reactants.

Any one of these steps may be rate controlling; however, proper selection of pore size distribution and sufficient porosity will minimize difficulties with the gaseous and ionic diffusion steps, i.e., steps 1, 5, and 6. Regarding step 6, it must be mentioned that serious trouble can result if the reaction product is not a gas, i.e., if it is a condensed phase. Discharge of the cell then results in blocking of the pores by the liquid (or solid) phase and further reaction is impossible. Certain hydrogen-oxygen cells suffer from this limitation.

Chemisorption can be enhanced by selection of electrode material for its catalytic properties or otherwise including catalysts in the pores. For example, a porous carbon electrode may be made into a good hydrogen electrode by dispersing throughout the electrode finely divided platinum metal. This provides the surface on which the hydrogen can be chemisorbed as hydrogen atoms.

The path by which the chemisorbed atom reacts with the ionic species in the electrolyte is a subject of much conjecture, and is an area in which a great deal more fundamental research is needed. Some of the possibilities are illustrated in Figures 1 and 2. However, the pertinent experiments to decide between the mechanisms have not yet been done. It is believed that hydrogen reacting at a nickel electrode in aqueous caustic follows a path similar to that suggested in Figure 1. Virtually nothing is known of the behavior of carbon monoxide at an electrode. A possible reaction path for oxygen reacting at an electrode in caustic electrolyte is shown in Figure 2.

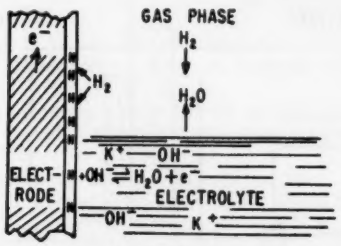


Figure 1—Suggested reaction mechanism for hydrogen at the anode in aqueous potassium hydroxide electrolyte.

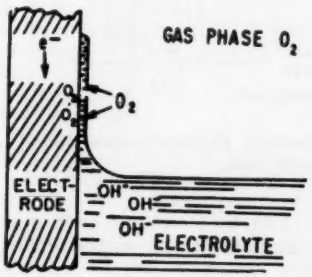


Figure 2—One suggested reaction path for oxygen at the cathode of a fuel cell diffusion of gas molecules through adherent electrolyte film.

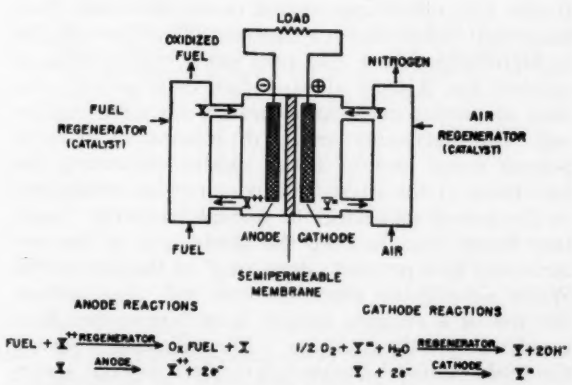


Figure 3—Schematic diagram of a redox fuel cell.

The selection of an electrolyte for a fuel cell is restricted by the requirement of invariance. This requirement is simply that the electrolyte must not change in composition or amount with cell operation. Ions consumed at one electrode must be re-

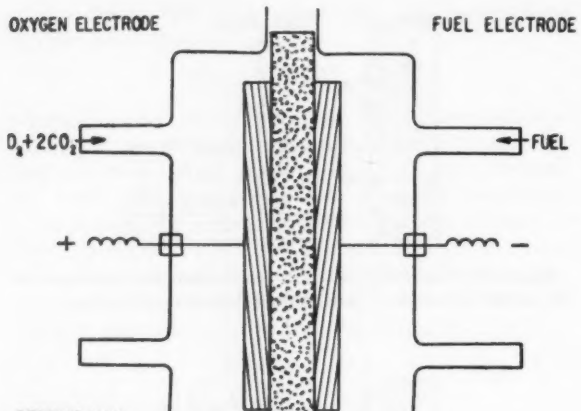


Figure 4—Ceramic matrix—molten alkali carbonate fuel cell in schematic form.

placed by reactions at the opposite electrode.

In the foregoing paragraphs, we have indicated that there are considerable difficulties involved in the design, construction, and operation of gas-diffusion electrodes. These difficulties have prompted fuel cell investigators to try other types of electrodes and other approaches to the fuel cell. Two important cases deserve mention. The first applies to high-temperature fuel cells using molten salts as electrolytes. Almost all such fuel cells consist of a disk of porous ceramic saturated with the molten salt. The electrodes consist of screens or disks of porous metal and/or metal oxides contacting the two faces of the disk. This is somewhat analogous to the use of separators in storage batteries. Capillary forces tend to keep the electrolyte in the ceramic and thus prevent "drowning" of the electrodes. While simplifying electrode and cell construction, the use of a ceramic matrix is certain to result in greater internal resistance in the cell. Also, a screen electrode cannot be expected to yield as high a current density as a true gas-diffusion electrode, inasmuch as there is much less active area per unit geometrical area.

A more radical departure from gas electrodes appears in the so-called redox cells. Here an intermediate substance in aqueous solution is reduced by the fuel and is then circulated over an inert electrode (anode) where it is oxidized, releasing electrons to the electrode. Similarly, an intermediate oxidant is oxidized by oxygen and circulated in an inert cathode and there reduced. Figure 3 shows a schematic redox cell. Posner in England has reported extensive studies of a redox cell using coal with limited success.[9,10] In 1948, Carson described a study of redox cells based on carbon monoxide.[11] The efficiency of these cells was poor chiefly because of a very low-voltage redox pair. While the electrode problem is solved by the redox approach —large current densities being achieved by suitable electrodes of graphite or nickel—many other difficulties are introduced. Chief among these is the problem of finding suitable intermediate redox couples, one readily reduced by a conventional fuel and the other readily oxidized by air, which will yield a high cell voltage.

STATE OF THE ART

Recent fuel cell development has taken two distinct paths. Efforts in one direction have been toward low-temperature (25-250°C) hydrogen-oxygen cells utilizing gas-diffusion electrodes. When operated with pure hydrogen and oxygen under pressure, these cells are characterized by very high specific power output. The most highly developed is the Bacon cell, invented by F. T. Bacon in England and being marketed in this country by the Patterson-Moos Division of the Universal Winding Company.[4] In this cell, the operating temperature is 200-240°C, which entails pressurizing the gases to 600-800 psi. Plaques of porous nickel serve as electrodes. About 6 mm thick, they contain pores averaging 30 microns in diameter on the gas side and 16 microns on the electrolyte side. Certainly, the Bacon cell is the most compact of the power sources. The very large current densities are to be attributed in part to the high pressure. Among the principal limitations must be mentioned the necessity for very pure hydrogen and the short life of the oxygen electrode. Regarding the latter, 1,500-hour runs have been achieved.

Another hydrogen-oxygen cell which has received publicity lately is that developed by the National Carbon Company.[12] The electrodes consist of porous carbon tubes impregnated with appropriate catalysts. Aqueous caustic is again the electrolyte. The claim is made that, in one version at least, the cell has successfully operated for periods well in excess of one year. There is no reliable information on the purity of the hydrogen required, particularly for long-term operation.

Our earlier considerations on fuel economics indicate the direction of the other path of fuel cell development, toward high-temperature cells which will operate on carbon monoxide containing fuels. The requirements of electrolyte invariance for such fuels is met by those containing carbonate ions. Molten alkali carbonates appear to be the most satisfactory choice. This path of fuel cell development has further split into two differing approaches to cell design. The first utilizes the aforementioned porous ceramic matrix to retain the molten salt as shown in Figure 4. Certainly, the most comprehensive study of this type of high-temperature cell

has been carried out in the laboratory of Prof. J. A. A. Ketelaar at the University of Amsterdam in The Netherlands.[13,14] His fuel cells show very encouraging results. An even more promising feature is a demonstrated life of at least 6 months at 650°C.

The second approach to the design of high-temperature molten carbonate cells is to use gas-diffusion electrodes in the free liquid electrolyte. At the Research Laboratory, the possibilities along these lines have been investigated. Progress to date has been encouraging but not spectacular in these cells, which are designed for convenience in testing electrode materials and structures rather than maximum output. We believe that gas-diffusion electrodes in the molten salt offer the best possibility of obtaining the 100-200 amperes per square foot required for a practical cell.

CONCLUSIONS

In closing, a few words about the future are in order. It seems quite safe to predict that the next year or so will see hydrogen-oxygen cells, based on gas-diffusion electrodes, in military and, somewhat later, in some civilian applications. Fuel cells for central station power lie further in the future; these will burn gaseous fuels containing carbon monoxide and, I believe, will be based also on gas-diffusion electrodes.

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Scheduled for launching on May 11, the FRANCE, the newest superliner, is nearing completion at St. Nazaire on the same launch ways where her predecessor, NORMANDIE, was constructed in 1933. The FRANCE will have an overall length of 1035 feet and a beam of 109 feet. Having a very fine hull form for high speed, her gross tonnage will be considerably less than that of NORMANDIE. Considerable use is being made of aluminum in her upper structure. She will be powered by four shafts rated at 40,000 SHP each at 165 RPM. Steam conditions are 925 psi and 900°F. Four pairs of Denny-Brown stabilizers will be provided. Her accommodations are listed at 500 first class and 1500 tourist class passengers.

—From THE MARINE ENGINEER & NAVAL ARCHITECT
November, 1959

It is sometimes thought that the galley, even in its later designs, was a cumbersome unwieldy vessel propelled mainly by sheer muscle, but details given by Prof. Ata Nutku in ***Bulletin No. 5*** of the Turkish Shipbuilding Research Institute, Istanbul, describe a craft with a block coefficient of 0.45. This galley is in the ***Kadirza*** class of Turkish galleys, the other two series being larger, the ***Mauna*** with 24 guns and 364 oarsmen and the ***Basterde*** carrying 20 guns and 500 oarsmen. Although slightly smaller than the average size of the ***Kadirza*** class the galley at Istanbul shows all the principal features of this design of craft. The craft is a royal galley, now housed in the Naval Museum at Istanbul and thought to have belonged to Mohammed III. There is a strong resemblance between this galley and those used in the siege of Constantinople, by Mohammed the Conqueror in 1453. The galley was equipped with 48 oars, with three men to each oar, and has a load water line length of 107 feet, a beam on the waterline of 14.5 feet and a loaded draft of just over 3 feet. The form of the vessel is reminiscent of a swordfish with a very long bowsprit about 17 feet in length and a large radius at the turn of bilge; the hull is very fine with an average block coefficient of about 0.45. The initial stability is good with a GM of about 4 feet in the light condition.

The ornamental work, as may be expected in such a craft, is elaborate and artistic and the whole vessel is made beautiful by magnificent carvings which, in the Sultan's quarters aft, are inlaid with mother of pearl, gilded nails, colored mosaics and valuable gems.

Apart from the historical aspect, perhaps the most interesting part of the article deals with the speed and resistance of the vessel. A 1/15 scale model was towed in a model basin and E.H.P. curves were drawn. Historical records show that the maximum speed of such a vessel when propelled solely by oars was about 9 knots and at this speed the model tests the total E.H.P. to be about 30, *i.e.* the useful H.P. per man is 0.21.

It is of interest to recall that Alexander in his 1927 I.N.A. paper on the "Propulsive efficiency of rowing" estimated the resistance of a "racing eight" and a "10-oar whaleboat" and from this calculated that the useful H.P. per man of the eight was 0.35 at a speed of 10 knots, and for the whaleboat 0.20 at a speed of 6.7 knots. These last figures show a great disparity but it must be remembered that the University Boat Race, for example, is rowed over 4.227 miles only and lasts for an average of about 20 minutes.

—from SHIPBUILDING AND SHIPPING RECORD
December, 1959

LIEUTENANT E. M. AVALLONE, USN

SUBMARINE DEVELOPMENT PRIOR TO WORLD WAR I

THE AUTHOR

graduated from the Naval Academy in 1952 and served a year on an attack transport in the Pacific. His next four years were spent aboard the submarines DOGFISH *and* SARDA *with the Atlantic Fleet. At present he is taking the Naval Construction and Engineering course at M.I.T. in Cambridge, Massachusetts.*

EARLY HISTORY

ON A QUIET EVENING in 1776 final preparations were being made to launch the first submarine attack in history. A crude spherical shaped craft had been built by David Bushnell in an attempt to break the English blockade at New York. The submarine was large enough for one man, and propelled by manually operated screws. It submerged by taking water into a small ballast tank, and ran just below the surface of the water with a small positive buoyancy. The craft was armed with an explosive charge which was to be fastened to the target's hull with a single large screw and exploded by a timing device. (Figure 1.)

The HMS *Eagle*, an English sixty-four gun frigate that was lying at anchor off Governor's Island, had been chosen as the target. Sergeant Ezra Lee of the Revolutionary Army maneuvered the craft against a strong current, and finally reached the frigate without being detected. Working rapidly he attempted to attach the holding screw to the target's hull, but without success. Moving to another section of the hull he tried again to attach the screw, but failed. With daylight approaching and four long miles to safety, Lee gave up the attack. Two subsequent attacks were made by Bushnell's submarine against English ships, both of which ended in failure. The submarine was made of wood, difficult to maneuver, and extremely limited in range requiring a towing boat to bring it close enough to launch an attack. Horizontal and vertical screws, rudder, and flooding and pumping were all controlled by the single operator making it difficult to maneuver the craft. Sergeant Lee's attack has been said to have failed because the explosive's screw was unable to penetrate the frigate's copper sheathing.[1]

The idea of a submarine was not a new one in 1776. As early as 1578 a William Bourne had published a book titled "Inventions and Devices" in which he describes a submarine in detail. Bourne discussed at length the military potentialities of submarines, and although no record exists of his ever having built a submarine, it is felt that he must have experimented with an actual submarine to have gained so much knowledge of one.[2] Credit for constructing the first submarine is given to a Dutch physician, Cornelius von Drebbel, who in 1624 built a craft propelled by oars. Experiments were conducted on the Thames River. The wooden craft was made watertight by the use of greased

leather and was maneuvered in the awash condition.[3] A succession of submarines were constructed between von Drebbel's submarine and Bushnell's diving bell, but all were small, ungainly, and lacked an efficient propulsion system.

The next step in submarine advancement was made by Robert Fulton while he was living in France in 1801. Combining his inventive genius with Bushnell's ideas, he designed a submarine in the form of an imperfect ellipsoid, 21 feet long, and 7 feet in diameter, constructed of copper with iron frames supporting the plating. A heavy detachable keel was used which could be released in case of emergency giving the craft immediate positive buoyancy. The craft was the type which flooded its ballast tanks to decrease its buoyancy until the buoyant force equaled the vessel's weight. Fulton constructed a small conning tower on his craft for the use of the controlling officer while running in the awash condition, and also used horizontal rudders forward and aft for control of the submarine in the vertical plane. A mast and sail were used for surface propulsion, and were rigged-in prior to diving. Submerged propulsion was provided by a two-bladed propeller rotated by a hand wheel which could also be used while surfaced. An explosive charge was towed by the submarine and was to explode on contact with an enemy ship. Compressed air stored in tanks provided enough air to allow the submarine to remain submerged for a period of five hours. A lack of financial support, and an unwillingness on the part of the French to use such a craft against the blockading English fleet, forced Fulton to abandon his experiments.[4]

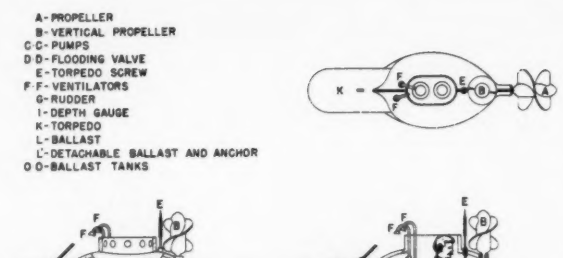

Figure 1. Bushnell's Boat.

PROBLEMS TO BE SOLVED

In spite of Fulton's limited success there were still many problems remaining to be solved before a submarine capable of operating at sea could be built. Early designers realized that the most efficient hull form should closely approximate that of a fish for efficient operation while submerged. Such a hull form provided little freeboard, and poor sea keeping qualities in even calm seas, but was used by all designers until about 1900.

A suitable weapon for submarine work was also needed to give impetus to submarine development. Bushnell's mine and Fulton's towed explosives required the submarine to actually pass under the target ship, and therefore, limited attacks to periods of darkness. Another weapon attempted was an explosive charge placed on the end of a long spar which was detonated by ramming the target. All of these weapons were crude, as well as dangerous to the submarine making the attack.

The most important factor limiting submarine development was the lack of suitable propulsion. Fulton had recognized the necessity of having some means of propulsion beside the manually operated propeller, and installed a sail for surface propulsion. A system which would permit the submarine to operate at submerged speeds equal to that of the surface ships of the day, and which consumed no oxygen was needed. Such a propulsion system was not available until the advent of nuclear power. The eventual development of the storage battery, however, temporarily solved the submerged propulsion problem, but an efficient surface propulsion system was also needed. Having only limited power available for submerged operations, the submarines of the nineteenth century were considered only for the defense of harbors against blockading ships.

With no means available for seeing the enemy after submerging, early submarines would run in the awash condition until fairly close to the target. Conning towers with watertight windows were built on most of the submarines. The submarines would be flooded down until the conning tower was awash, and remain in this condition until fairly close to the target. Once the controlling officer was sure he would not miss his target, he could submerge his craft, and make the attack. Once submerged, the controlling officer could not be sure of the course he was making good since the accuracy of the magnetic compass in an enclosed metal hull with operating equipment left a great deal to be desired. Sub-surface navigation did not attain any degree of accuracy until the periscope and gyrocompass were perfected about 1910.

Another problem confronting the submarine designer was the lack of longitudinal control of a submerged submarine. A ship on the surface of the water needs only a rudder for control in the horizontal plane, but once submerged a method of control in the vertical plane was needed. Bushnell had used a crude, manually operated, vertical screw to control his submarine in the vertical plane. Fulton preferred to use two sets of rudders placed horizontally in pairs forward and aft to control his

vessel vertically. The vertical screw was inefficient while Fulton's horizontal rudders did not respond rapidly enough, and required the vessel to have a forward motion in order to function properly.

Submergence in all the submarines built was attained in either of two ways. The method preferred by most designers was to keep a small positive bouyancy, and force the vessel under with forward motion and vertical controls. The second method was to flood the ballast tanks until a negative buoyancy was obtained which caused the boat to sink slowly. When the desired depth was reached, enough water was pumped from the tanks to attain neutral buoyancy. The ballast tanks were also used to compensate for weight changes on the submarine. As fuel and consumables were added or removed, water would be pumped out or flooded into the ballast tanks to maintain the desired buoyancy condition. In either method a large free surface remained in the ballast tanks of the submarines developed. It was not until 1900 that the problem of free surface was sufficiently minimized, and vertical controls sufficiently developed for submarines to be stable longitudinally.

WARTIME USE

Realizing the tremendous military advantage of being able to approach an enemy ship without being seen, designers continued to attempt to build efficient submarines throughout the nineteenth century. In the eighty years after 1800 there were many submarine designs, but they showed little real advancement because of the lack of a suitable means of underwater propulsion. It is interesting to note that even though a successful submarine had not been developed, the threat of possible submarine attack was extremely influential in military thinking throughout the nineteenth century. In 1850, a submarine built at Kiel, Germany, by William Bauer, was successful in causing the Danish blockading fleet to withdraw after making only one unsuccessful attack. Bauer's submarine submerged by flooding to a neutral buoyancy and moving a heavy weight forward while in motion. This gave the boat a downward inclination, and as soon as she started down the weight was moved back. This process was repeated until the desired depth was attained. Bauer was never able to obtain good vertical control, and was forced to abandon his experiments for lack of funds.[5]

During our own Civil War the Confederacy used two different types of submarines in defense of Charleston Harbor. The first type, called "Davids," was actually a torpedo boat propelled by steam, and operated in the awash condition. The second type, called "Huntleys," was designed to submerge, and was manually propelled by a crank and screw. A great deal of concern to the Federal ships blockading Charleston was caused by the presence of Confederate submarines in the area. A head of steam was maintained on all steam vessels, all anchors were rigged to be easily slipped, and extra watches were posted on all ships of the blockading squadron. In spite of these precautions, a Confederate submarine running on the surface succeeded in sinking the Federal steam sloop, *Housatonic*.[6] The Confederate craft were extremely unstable longitudinally, which resulted in many lives being lost in attempting to operate them. An explosive charge carried on the end of a spar was the armament of these craft.[7]

EARLY TECHNICAL ADVANCES

In 1863, the French built a submarine called the *Plonguer,* a vessel having a length of 136 feet, and a displacement of 450 tons. The hull was constructed of iron, and water ballast was carried in tanks in order to regulate the buoyancy. By means of a compressed air engine this vessel obtained a speed of five knots submerged, and used compressed air for water ballast removal for the first time. The *Plonguer* was a great improvement over previous designs, but the method of propulsion, and the longitudinal stability proved unsatisfactory.[8]

The year 1859 might be considered a milestone in submarine development for it was in 1859 that Plante first put forth a lead storage battery. Here was a device which could supply power for propulsion without using oxygen. It wasn't until the late 1880's that Plant's battery was developed to the point where it could be used for submarine propulsion. This development was eventually to make the submarine a practical warship.[9]

A crude self-propelled torpedo was built in 1864 by Captain Luppis of the Austrian Navy. With the aid of an Englishman, William Whitehead, the Luppis Torpedo was rapidly improved, and by 1870 it was capable of making eight knots for 300 yards.[10] With the development of a depth-controlling mechanism by Whitehead, and the installation of a gyroscope, the torpedo became an accurate weapon at short range. The Whitehead torpedo, as it was called, finally provided a weapon for submarine use which when detonated was not dangerous to the attacking submarine. It was no longer necessary for a submarine to go alongside or pass under a target during an attack, for by 1880, the Whitehead tor-

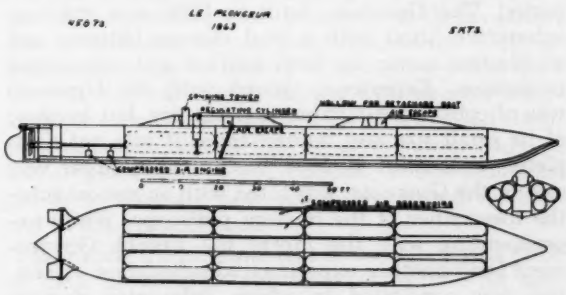

Figure 2. ***Plongeur.***

pedo was capable of travelling 800 yards at thirty knots with a reasonable degree of accuracy.[11] A leading English naval officer of the day, Admiral H. J. May, considered the Whitehead Torpedo of such importance to submarine development that he wrote, "It is the combination of the submarine and the torpedo that is so valuable, but for the Whitehead, the submarine would remain an interesting toy and but little more."[12]

LIMITED SUCCESS IN NEW DESIGNS

With the development of the battery for submerged propulsion, and the Whitehead Torpedo for submarine armament, renewed interest in submarine development was born. The period from 1860 to 1900 brought a standardization of the fish-like form, new attempts to conquer the problem of longitudinal stability, and a large step toward a surface propulsion system.

From 1885 to 1888, Nordenfelt constructed boats which operated quite successfully on the surface and in the awash condition, but were complete failures submerged. (Figure 3.) Due to free surface effect in the ballast tanks, and lack of suitable control by the vertical propellers, they either rested on the bottom, ran awash, or cycled between these two extremes. Their propulsion system consisted of a steam reciprocating engine fed by a coal fired boiler. Submerged, the fires in the furnace were killed, and the energy for the engine was obtained from the heat remaining in the boiler and the steam. Nordenfelt's submarines were the first fitted with torpedo tubes for firing Whitehead Torpedoes.[13]

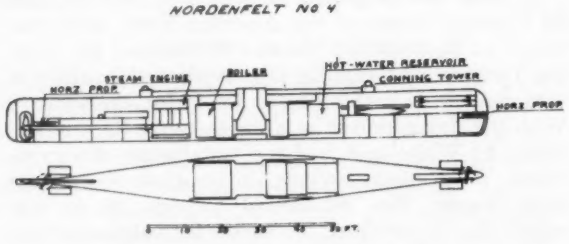

Figure 3. Nordenfelt Number 4.

A number of rapid advancements in the submarine development were made in France about this period. The *Gymnote,* built in 1886, was the first submarine fitted with a lead storage battery, and an electric motor for both surface and submerged propulsion. Experience gained with the *Gymnote* was of considerable value to designers, but because of its small size and limited speed it was not completely successful. In 1898, the *Morse,* a larger version of the *Gymnote,* was fitted with an optical tube, the forerunner of the modern periscope. While experimenting with the *Morse* the French Government built another experimental submarine. A contest was conducted in which submarine designs were submitted for consideration to the French Navy. The plans of M. Laubeuf were selected, and the *Narval* was built. (Figure 4.) Launched in 1899, the *Narval* was the first of the so called submersibles. The submersible is built with a hull-form resembling that of a surface ship in order to obtain better sea-keeping qualities. A submarine, on the other hand, has a hull-form resembling a fish, and has poor sea-going qualities on the surface. All the submarines built after 1914, until the advent of the Guppys after World War II, were of the submersible type, but the name submarine prevailed.

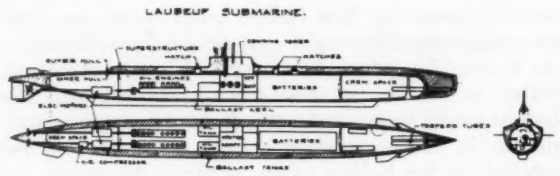

Figure 4. Laubeuf Submarine.

Another important milestone in submarine development was the *Narval's* tank arrangement. She was the first doublehulled submarine with a strong inner hull of elliptical shape, and a light outer hull of ship-shape form. The length of the ship was 112 feet, the beam twelve feet with a displacement of 117 tons on the surface, and 202 tons submerged. An oilburning boiler furnished the steam for a 250 horsepower triple expansion engine for surface operation at twelve knots. A submerged speed of eight knots was possible with propulsion being provided from storage batteries. Provisions were made for running air compressors and charging the batteries from the main plant.[14] Baffles in the ballast tanks, an increase in area of the bow and stern planes, and a more efficient plane control system overcame the longitudinal control problem in the first submarine of the *Narval* class. A period of twelve minutes was required to secure her steam plant before diving, and this was considered excessive for military purposes. In spite of this, Laubeuf's design served as a pattern for the German and Italian submarines, and is considered the prototype of the modern submarine.

Paralleling the submarine development in France, Simon Lake and J. P. Holland were in active competition for Government contracts in the United States. The two types proposed by these men were radically different. Holland, who had been experimenting with submarines since 1878, received a Navy contract in 1895, and began construction of the *Plunger.* Due to unrealistic requirements imposed by the Government contract, the *Plunger* was never completed. The Holland Company, at its own expense, built and sold the Navy the *Holland* in 1899. (Figure 5.) This boat was fifty-three feet in length, ten feet in diameter, and displaced seventy-five tons. A fifty horsepower Otto-cycle gasoline en-

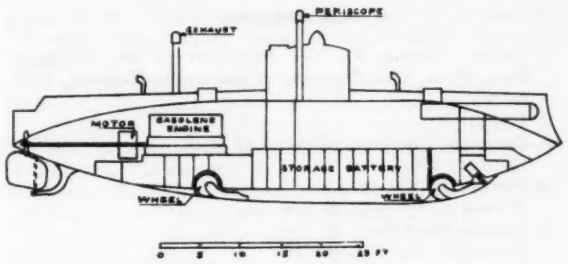

Figure 5. The *Holland*.

gine was used for surface propulsion. Beside the gasoline engine, a 2000 pound per square inch air system, a trim pump, air compressor, and pneumatic machinery for steering and plane controls were incorporated in the *Holland*. The *Holland* was of single-hull construction, and was provided with a periscope. A positive buoyancy was maintained, and diving was accomplished by driving the boat under at a sharp angle.[15]

To compete with the *Holland*, Simon Lake built the *Protector* (Figure 6) which was propelled by a gasoline engine and batteries. Lake's boat had several extremely novel ideas, some of which are in use today. There were wheels for travelling along the bottom, a compartment from which divers could leave and enter the submarine, a primitive snorkel for engine operation submerged, double-hull construction with fuel tanks outside the pressure hull, and an escape hatch in the Conning Tower. A crude periscope was also installed in the *Protector*. The Holland became the type selected by the Government for further development, and it became the prototype for the submarines subsequently built in England and the United States.[16]

Seeing the successful adoption of steam propulsion for other type vessels, the submarine designers turned to steam for the solution of their propulsion problems. Although steam propulsion greatly increased the operating range for submarines, it had two distinct disadvantages. First, diving was delayed for about ten minutes in order to secure the steam plant, and secondly, the submarine was made almost uninhabitable after submerging because of the extremely high temperatures. Holland's employment of the gasoline engine was a large step toward the solution of the submarine surface propulsion

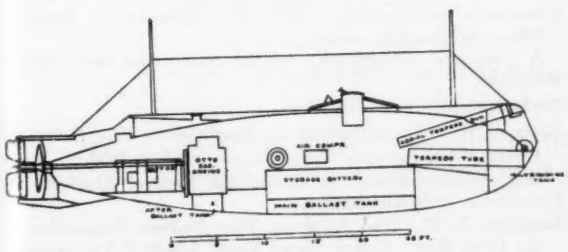

Figure 6. The *Protector*.

problem, and was immediately adopted by all countries. The employment of the gasoline engine greatly reduced diving time, provided greater horse power per unit weight, emitted less heat after submerging, and was quickly started and shut down. Gasoline as a fuel was not particularly desirable, however, for the danger from explosion and carbon monoxide poisoning was always present. Due to the limitations of gasoline as a fuel, another method of propulsion was being sought.

THE FINAL DEVELOPMENT

Germany entered the submarine construction competition in 1903 when the Krupp Company built an experimental boat of the double-hull type. By 1906 the Krupp Company had abandoned the gasoline engine, and was using a Korting heavy oil engine for surface propulsion. Due to the Korting engine's large consumption of fuel, and its inability to provide sufficient propulsion power for the larger submarines being built, the Krupp Company by 1910 had developed the Diesel engine. The Diesel was the last step in the development of submarine propulsion. Although heavier than the gasoline engine, its fuel consumption was somewhat less, and the danger of explosive gas fumes was eliminated.[17] With an efficient engine for surface operation, ability to carry a large volume of fuel outside the pressure hull in the double-hull design, and good seakeeping qualities of the submersible, the submarine became a potential warship.

Two additional developments were made about 1910 to complete the technical advances necessary for successful submarine operation. An efficient periscope was finally developed during the period from 1900 to 1910 from the crude optical tube designed by Marie Davy in 1854.[18] The problem of submerged navigation was solved with the development of an efficient gyroscope which was not affected by the ship's hull and operating machinery.[19]

In the short period from 1900 to 1914 the submarine was developed from an experimental craft into an efficient fighting machine. The submersible hull form of steel construction was universally adopted. Free surface effect was eliminated by completely filling the ballast tanks. A fore and aft trim tank, and an auxiliary tank amidship were constructed inside the pressure hull. Variation in displacement due to fuel consumption, and consumables could be compensated for by adding or removing water from the internal trim tanks. Diving with neutral buoyancy on almost an even keel finally had been adapted as the best method of submerging. The fore and aft pairs of horizontal rudders, or bow and stern planes as they are now called, were used for control in the vertical plane.

In tracing the development of the submarine prior to 1914, no attempt was made to include all submarines designed or constructed. Those designs selected are generally accepted as milestones in this

evolution. To attribute the development of the submarine to the men closely associated with these milestones would be a great injustice to others who also contributed significant advances. Each of these contributions was necessary for the submarine to reach its 1914 stage of development.

The development of a submarine which was capable of taking a permanent place as a warship was delayed until certain technical advancements had been completed. A satisfactory battery for submerged propulsion, the diesel for surface propulsion, the gyroscope, and an efficient periscope were all advancements which had not been sufficiently developed before 1910 to be incorporated into submarine construction. By 1914 the Whitehead Torpedo was able to carry a 300 pound warhead 8,000 yards, making it an excellent weapon for submarine use.

If a successful submarine had been developed prior to 1900, it undoubtedly would not have been useful as a warship. The range of operation was limited by a poor propulsion system. Poor longitudinal stability limited submarine operation to shallow water. With no periscope, and a poor gyroscope, submarines were unable to remain submerged for any length of time without the fear of running aground. With so many limitations imposed upon early submarines, ships could easily defend themselves against submarine attacks. The success of the Confederate submarine in sinking the *Housatonic* during the Civil War was actually due to unusually good luck on the part of the submarine. Some forty lives had been lost in attempting to operate submerged, so the entire attack had to be made on the surface. Enough time elapsed, between the time the submarine was sighted and the charge exploded, to call the crew to quarters, and man the guns. If one of the watch had been successful in killing the officer guiding the submarine, who was in plain view, the attack probably would have been thwarted. At any rate the submariner's luck was but temporary, for all hands went down with the submarine when the charge exploded.

With the completion of the last of the necessary technical advances early in the twentieth century, the submarine was ready to prove its worth. A new form of warfare was to be developed to defend against this new addition to the fleet. The necessity of protecting larger ships against the always imminent submarine attack had to be considered at all times. Harbors could now be defended by small submarines. The submarine could be used as a scout for surface task forces. Submarines were ideal for use as commerce raiders. With the ability to remain at sea for extended periods, and staying submerged during daylight hours, the submarine was difficult to find and destroy. The stage was set, and the First World War was to be the test, for the submarine was ready to prove itself a deadly and efficient man-of-war.

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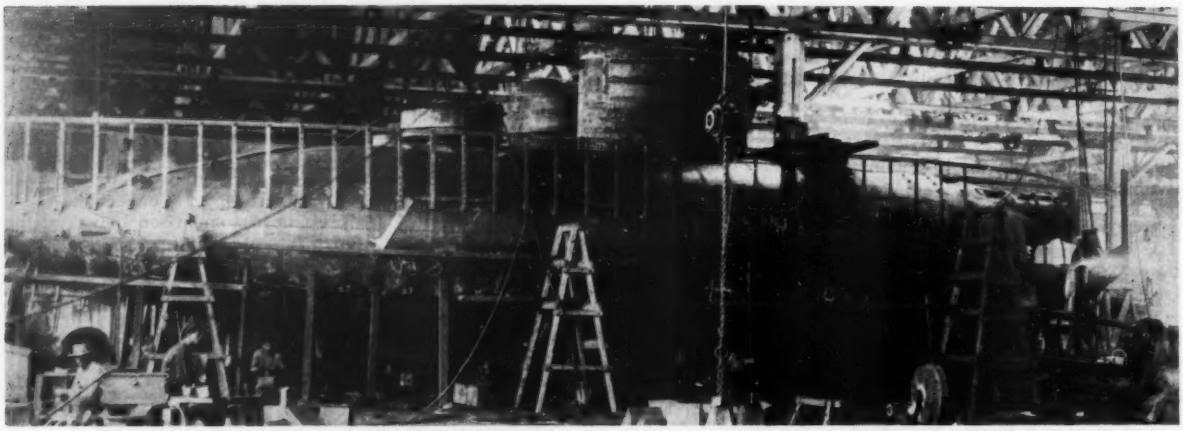
Ultrasonic bonds of structural integrity have been produced in bimetal combinations of many of the high-temperature refractory metals and alloys such as titanium, zirconium, molybdenum and the precipitation-hardening stainless steels—materials of particular interest in the design of aircraft, missile, rockets and nuclear reactors.

Electrical connections, such as the attachment of leads to coils or contact buttons to a variety of configurations, are readily produced with combinations of silver, copper, aluminum and other materials. Good quality junctions of excellent conductivity are reproducibly achieved, even through certain insulating coatings.

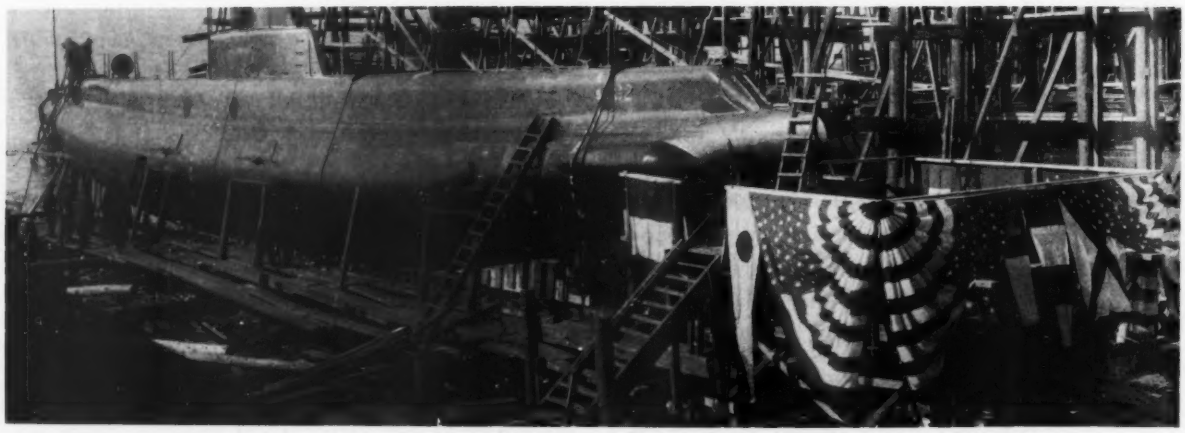
The process is also effective for precision joining of very fine wires and thin foils to materials such as transistor elements or certain types of printed circuits, without the unacceptable contamination resulting from certain fusion-joining methods. The assembly of electronic-tube, bridgewire and precision-instrument components present other significant possibilities.

—from WELDING JOURNAL
February, 1960

Early Submarines at Newport News



Five Submarines under construction at Newport News in 1904. They were only 73 feet in length and had a total weight of only 130 tons. They were cut into sections and loaded aboard vessels for shipment.



Submarine *Tuna* ready for launching. She was 161 feet in length and had a beam of only 13 feet.

Miss Marjorie Miller, sponsor of the submarine *Tuna* which was launched at Newport News on January 10, 1912.

"ENGINEERING"

CONFUSION IN MEASURING SURFACE ROUGHNESS

ACKNOWLEDGMENT

This article, by M. I. Rubert, is reprinted from the October 23, 1959 issue of "Engineering."

ROUGHNESS AND smoothness are clear concepts to everybody, since we practice tactile comparison from the first day of our lives. Whether we inspect articles of wood or metal, textiles or plastics, paper or leather, quite subconsciously we touch them because visual inspection alone does not give all the information we want.

Our ability to assess surface quality by tactile comparison is therefore highly developed, and no doubt very helpful in keeping the surface roughness within certain limits, without using instruments. On the other hand, it is precisely the same obvious concept of roughness which so often causes confusion and renders the whole field of surface roughness measurement ambiguous and unscientific. The difficulties in reaching international agreements on definitions and standards are probably due to the same cause. The methods we are using at present to define and evaluate surface roughness very often contradict our natural concepts of the idea (which is, broadly speaking, equivalent to the frictional qualities of the surface) and this applies to all national standards of roughness evaluation.

Before discussing the various national standards we need to know the basic definitions. There are two ways of defining surface roughness. There is first a geometrical method which gives a numerical value to the deviation of the profile from a reference line. In this case, the original three-dimensional problem is reduced to one of two dimensions. The second definition is functional, and gives a quantitative designation to certain physical actions or effects influenced by surface roughness, e.g., pressure variation in a pneumatic circuit, reflection of light and friction. In this case, three dimensions may be explored simultaneously. Since the standardization of instruments and their readings using the latter alternative led to innumerable problems, an international agreement was reached to adopt the former geometrical definition. (See the report of the meeting of working group R of the International Institution for Production Engineering Research in Vienna, 1958.)

The basis of the geometrical definition is the line from which the deviations are considered, and there are two possibilities at present causing considerable

controversy. These are the mean or center line, and the envelope line.

The system based on the mean or center line is called the M system, while that based on the envelope line is called the E system. The letters M and E have been internationally adopted, but this is unfortunately the only point on which agreement has been reached with regard to the two systems.

MEAN LINE

BS 1134 defines the mean line as, see Figure 1(a), "A line conforming to the prescribed geometrical form of the profile and so placed that the sum of the squares of the ordinates between it and the profile is a minimum" and this mean line is the reference line from which the deviations of the profile are evaluated. The E system, see Figure 1(b), is based on an imaginary line, which is generated by the center of a sphere of radius R, when it is rolled over the crests of a surface. This line is then lowered by the distance R, so that it rests on the peaks of the surface. The construction of the E line is very simple. Ordinates are drawn through the highest peaks, e.g. at A and B in Figure 1(b), normal to the ideal geometrical line. With C_A and C_B as centers, circular arcs of radius R are drawn which form the E line. This construction presupposes a graph recording with equal horizontal and vertical magnification. Most instruments, however, provide only highly distorted recordings, with the vertical magnification up to 500 times greater than the horizontal magnification. Thus the circular arcs are distorted into an elliptical form. In addition, with a recording which does not distort, i.e. which gives an H:V magnification ratio of unity, but merely magnifies, the arc will appear, over a short distance, as a straight line. Such a recording is found very useful when a true picture of the surface is required.

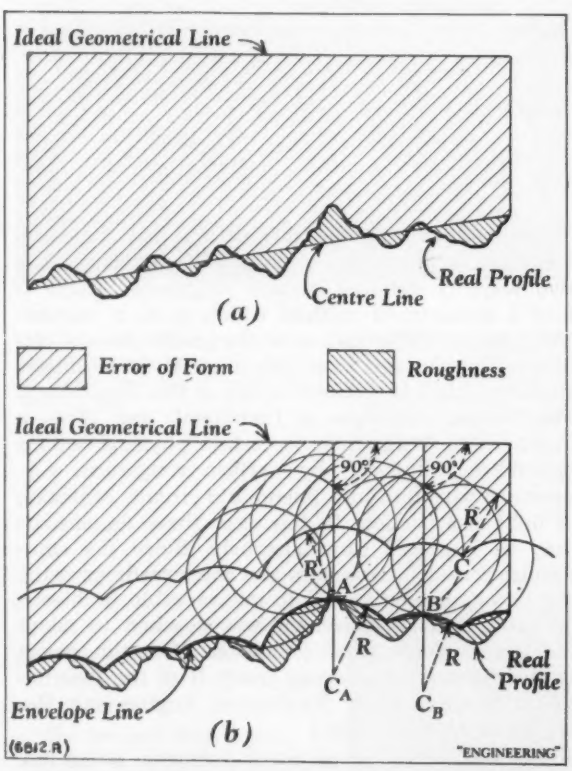


Figure 1. Geometrical definitions of surface roughness: (a) the mean or center line, and (b) the envelope line.

Very strong feelings have been expressed for and against the E system. Mr. R. E. Reason (England) claims that it cannot be embodied in present-day instruments, since the sphere of the measuring instrument cannot touch the surface at the same point and at the same time as the stylus. The countering argument, that the stylus instruments based on the M system operate by means of a skid traveling along the E line, and thus tend to meet the requirements of the E system, is less convincing since these instruments integrate the numerical values based on the center line, and therefore the relative position of the stylus to the skid is of lesser importance. Another point against the E system is that stylus instruments operate in the field of two dimensional geometry and therefore the sphere creating the E line should be reduced theoretically to a two-dimensional disc, and for practical purposes the thickness of the disc should not be larger than the radius of the stylus tip. This limitation cannot easily be embodied into an instrument since it would have a thickness of from 0.0001 inches to 0.0005 inches. If the sphere is used instead of a disc, and the peaks immediately on either side of the line being explored are larger than the highest peaks along the line, errors will be introduced.

METHODS COMPARED

Von Weingraber (Germany) and Bickel (Switzerland) are of the opinion that the M system is inadequate in many respects, but mainly because of the great difficulties in determining the actual position of the M line, since it requires at least six planimetric evaluations. This is impracticable, and generally, direction and position are only assessed. The M system is therefore condemned as being inaccurate and unscientific. Although this criticism is factually correct, it is in the writer's opinion unrealistic since the whole field of surface roughness evaluation is far from being an exact science as yet. The adoption of the E line would bring little advantage to the practical engineer, and there are many other problems to be solved, mainly of a functional nature, which are more important in surface roughness control. This, however, does not mean a condemnation of the E system. There is no doubt that it offers many advantages, of which the most important is the clear and unambiguous separation of roughness, waviness and error of form, which the

Standard	Formula	Used In
Maximal Depth	$R_{max} = (y_{max} - y_{min})$	Germany Austria Switzerland Italy Sweden Jugoslavia Poland Czechoslovakia Russia Belgium
Mean Depth	$R_m = \frac{1}{2}\int_0^l y\,dx$	Germany Austria
Depth of Smoothness	$R_p = G = R_{max} - R_m$ G stands for Glattungstiefe (German)	France Germany Switzerland
Arithmetical Average	$CLA = \frac{1}{2}\int_0^l \lvert y \quad R_m \rvert\,dx$	Gt. Britain USA Holland Spain France
Geometrical Average (Officially Abandoned by USA, but Still Used)	$RMS = \sqrt{\frac{1}{2}\int_0^l (y - R_m)^2\,dx}$	USA Russia Poland Czechoslovakia
Peak to Valley Average (Although Recommended by BS 1134, Very Rarely Used)	$PVA = \frac{(H_1 + H_3 + \cdots H_9) - (H_2 + H_4 + \cdots H_{10})}{5}$	Britain
Percentage Bearing Area	$B_A = \frac{L_1 + L_2 + L_3 + L_4}{l}\,100\%$	Germany Switzerland Austria
Swedish Standard	$H_{SMS} = (X - Y)$ Lines X and Y Positioned so that $\Sigma P = k_1 L$ $\Sigma V = k_2 L$ Swedish Standard Appoints $k_1 = 0{\cdot}05$ $k_2 = 0{\cdot}10$	Sweden

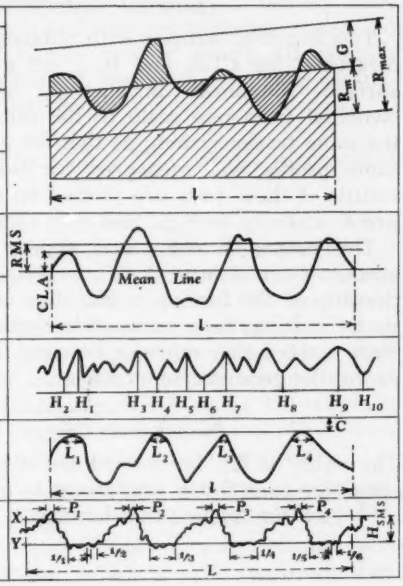


Figure 2. Eight standards for measuring surface roughness, showing the countries in which each is used. For countries which use more than one standard, the one chiefly used is indicated by underlining the country's name.

M system does not provide, as can clearly be seen from Figure 1 where, in (*a*), illustrating the M system, the error of form includes a part of the roughness and waviness, which is not the case with the E system. Before adopting the E system, however, considerable research work has to be done with regard to the most typological information obtainable from the existing standards.

There are, at present, eight national standards as listed in Figure 2. For countries which use more than one standard, the one predominantly used is indicated by underlining the appropriate name. (There are a few more systems which only express relationships between the quoted standards.)

There is no doubt that none of these gives a complete answer to all the problems involved in surface roughness evaluation, and at present it is difficult to say which of them provides the greatest information about the functional qualities of the surface. It is, therefore, becoming increasingly obvious to many engineers who take the surface roughness problem seriously that instruments are necessary to measure more than one standard to fulfill every surface requirement of precision engineering.

In Britain, and lately also in the USA, the CLA (Center Line Average) method, which is described in BS1134: 1950, is defined as "the average value of the departure of the profile from its center line, whether above or below it throughout the prescribed sampling length." This is the arithmetical average, which has no mathematical relationship to the total depth, and as will be shown later varies from about a quarter to one-twelfth of the actual depth.

The CLA method has great advantages: its instrumentation is easy, the dispersion or scatter is relatively small (only 10 per cent to 30 per cent) and in most cases CLA readings agree with the results obtained by tactile comparison and consequently with our natural concept of roughness. There are, however, some cases, and unfortunately they are not rare enough to be ignored, where the CLA method fails completely.

Figure 3 shows a well-known example of two surfaces, which measured with a CLA reading instrument give the same value, and since CLA is supposed to give a quantitative designation to the surface quality, we are asked to believe that both surfaces are of the same quality. The argument, that this is an extreme case which exists only in theory and does not represent any known machining process, is fallacious. While admittedly the diagram illustrates an extreme case unlikely to occur in practice, there exist many actual surfaces closely approximated to the ones shown. Surfaces produced by any machining process, which are afterwards finished by another process, whether it be lapping, honing or papering, often produce characteristics closely resembling Figure 3.

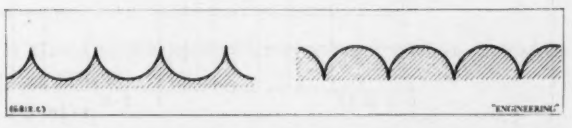


Figure 3. Two obviously different surfaces which give the same CLA reading.

TESTS ON SAMPLES

Two hundred samples with different finishes were measured for CLA and $R_{max.}$ on a Perth-o-meter surface roughness instrument, which can be switched from one scale to the other while using the same tracer system; so that for each sample the same profile was measured for both scales. The results of these tests are plotted on the graph, Figure 4, where $y = R_{max.}$ and $x = CLA$.

The points on the graph appear to lie around straight lines sloping at 45°, implying a linear relationship of the form $y = Kx$. The set of points for each finish has been enclosed between parallel lines, with a third line midway between each pair indicating the geometrical average,

$$K_{av} = \sqrt{K_{max.} \times K_{min.}}$$

The value of K_{av} for these lines of geometrical average for each finish was found to be:

8.6 for lapping and honing,

6.7 for grinding, and

4.5 for turning and shaping.

The results above are useful as a first approximation, but closer inspection tells us that a line of slope of rather less than 45°, say $\tan^{-1}(1-e)$ would give a more accurate result, this is because the distribution of points around the average line is not uniform. It can be seen, for lapping and honing between 1 and 15 micro-inches CLA, the lower half of the envelope holds three times as many points as the upper half, while between 0.3 and 1 micro-inch CLA the distribution is reversed: the majority of points being in the upper half. The same proportions applied to the two other finishes. This revelation necessitates the modification of the original equation into the following form:

$$\log y = C + (1-e)\log x,$$

where C is a constant. Taking antilogs

$$y = C' x^{1-e}$$

where $\log C' = C$.

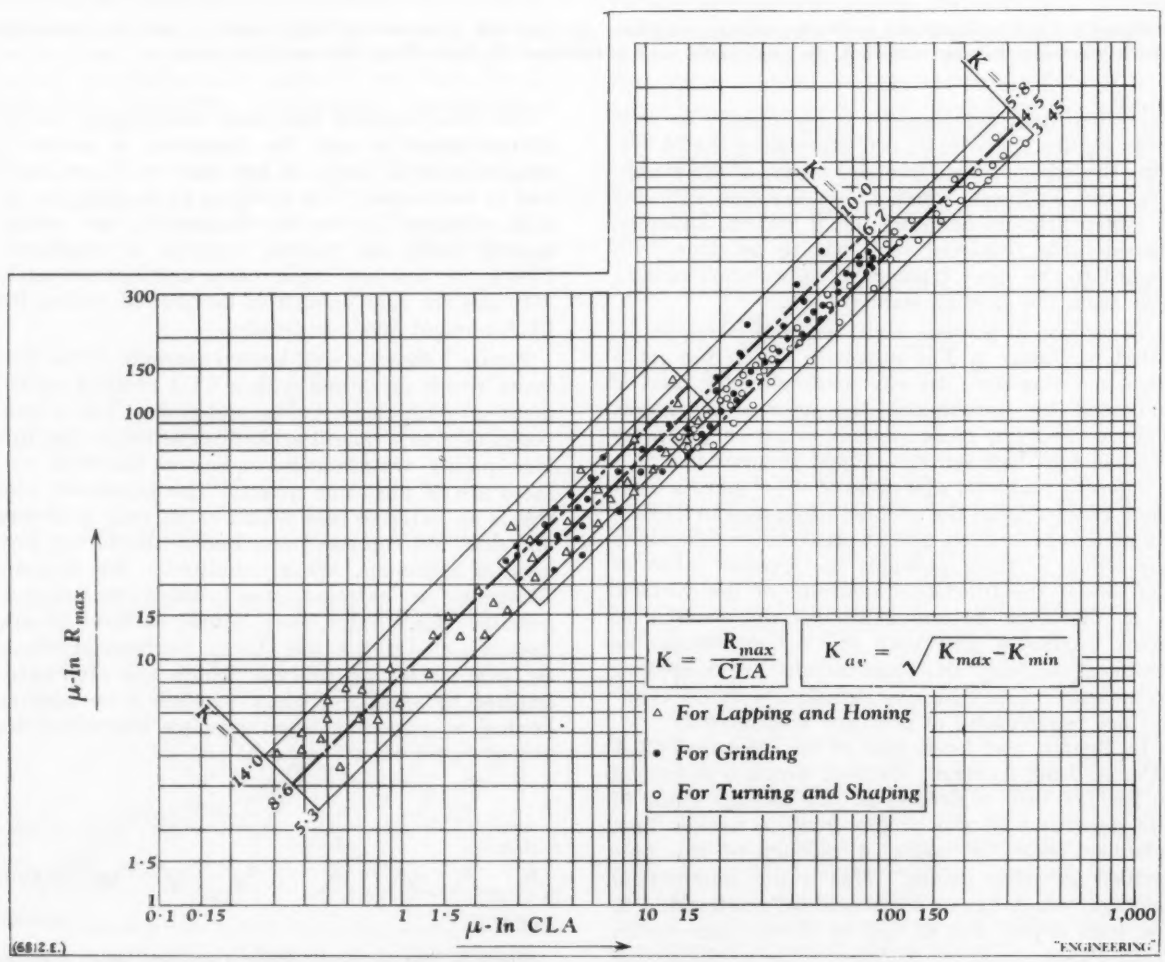


Figure 4. Results of tests on 200 samples.

whence $K=\frac{y}{x}=C' x^{-e}$

or, taking logs,

$$\log K=\log y-\log x=C-\log x.$$

This shows that a graph of K plotted against x on logarithmic paper will be a straight line of slope $-e$, which, within the limits of accuracy of the measurements, appears to be the same for all types of finishes, namely, 0.15. Straight lines thus obtained are shown in Figure 5.

It is interesting to note that the lines for lapping and honing and for grinding coalesce, while the line for turning and shaping is separate and lower down the graph.

Unfortunately, there were not enough test samples available above 350 micro-inches CLA, but four between 400 and 1,000 micro-inches showed that the straight line could be continued. It will most probably be accurate enough up to 1,000 micro-inches, when K=3.5. The line for honing and lapping and for grinding, however, cannot be continued above 90 micro-inches CLA because above this value results were found to be erratic, giving the errors for K in excess of 40 per cent.

The graph Figure 5 then gives $R_{max.}$ for any CLA value between 0.3 and 350 micro-inches within an accuracy of ± 40 per cent in nearly all cases, a quite workable limit in the field of surface evaluation (see BS 1134:1950).

Since the values of $\frac{R_{max.}}{CLA}$ found in practical engineering range between 3.5 and 14, it is hopeless to choose an average value. The practice of some firms, therefore, of marketing surface roughness measuring instruments reading CLA and $R_{max.}$ on the same scale, without computing each value separately, is highly regrettable. One very well known firm, for example, markets an instrument claiming an average value of K to be 3.7, which is satisfactory for turned finishes above 125 micro-inches, but absolutely useless for finer work.

Engineers having dealings on the Continent, where $R_{max.}$ is the predominant standard, with few exceptions, will find Figure 5 very helpful, and where more accuate information is required, they will see that an instrument reading $R_{max.}$ and CLA separately is called for.

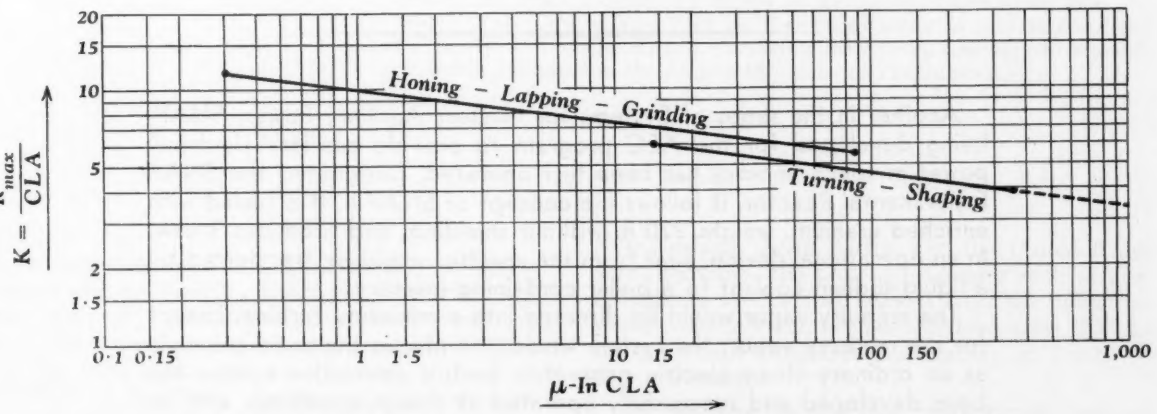


Figure 5. Values of K plotted against CLA value for different surface finishing processes.

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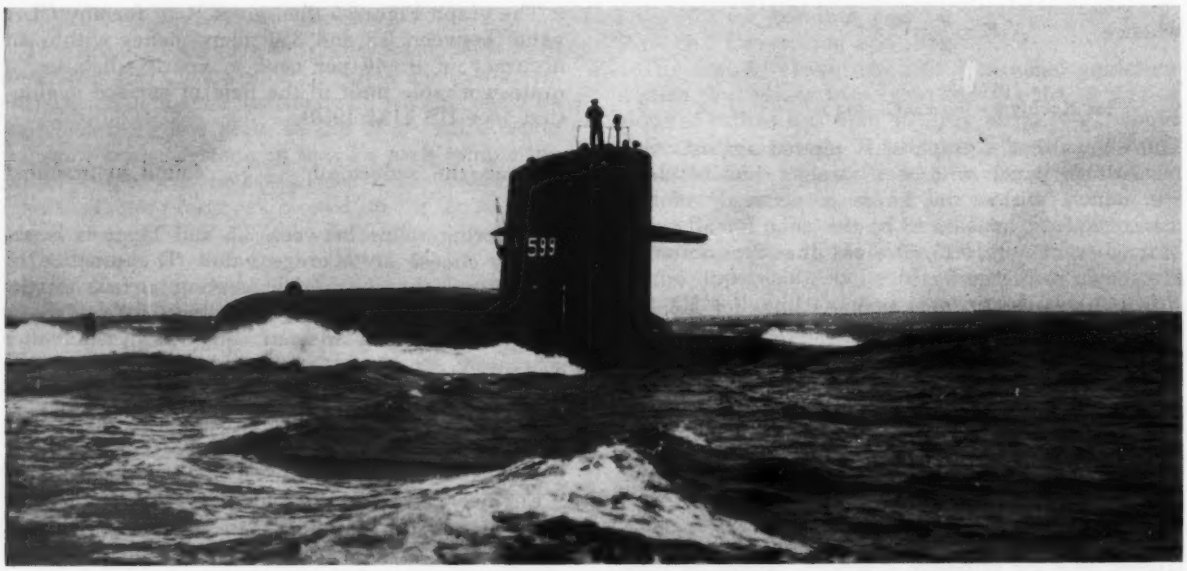


General Dynamics Corporation Photo

The nuclear-powered *Patrick Henry*, second of the Polaris-firing Fleet Ballistic Missile submarines, plows through the waters of Long Island Sound on her return on 9 March to General Dynamics Corporation's Electric Boat Division after two days of successful sea trials off the East Coast. On the bridge is the missile sub's commanding officer, Cmdr. Harold E. Shear of Shelter Island, L. I. Both the *Patrick Henry* and the *George Washington*, first of the FBM subs, will team up with the 1,200-mile Polaris this year. They will be capable of launching the missile from submerged positions.

Another in the series of Systems for Nuclear Auxiliary Power, SNAP, being developed for the AEC program to provide auxiliary electrical power in space vehicles has been test operated. Designated the SNAP Experimental Reactor, it follows the concept of SNAP II. It is fueled with enriched uranium, weighs 220 lb without shielding, and produces 3 ekw. In an operational device, heat from the reactor, would be transferred by a liquid-sodium coolant to a boiler containing mercury.

The mercury vapor would be directed into a miniature turbine. Except for the mercury vapor, the system would operate on the same principle as an ordinary steam-electric generator. Such a conversion system has been developed and successfully operated at design conditions with an electrical heat source.

The objective of the SNAP reactor program is to provide devices which will generate many kilowatts of electrical energy for a minimum period of one year in space and which will weigh no more than a few hundred pounds. The device must be capable of withstanding the shocks and vibrations of a missile launch, must be capable of unattended, reliable, and automatic operation in a space environment, and must not present a radiation hazard. Such a device would make possible long-lived weather satellites, world-wide TV communications, deep-space information transmission, and eventually interplanetary travel.

—from MECHANICAL ENGINEERING
January, 1960

ARNOLD BUCHSBAUM

ENGLISH AND METRIC SYSTEMS CAN CO-EXIST PEACEFULLY

THE AUTHOR

is a supervisory Marine Engineer at the New York Naval Shipyard. He is Head of the Heating, Ventilating and Air Conditioning Section of the Design Division. He holds a bachelor's degree in Mechanical Engineering from the College of the City of New York and has taken graduate courses there and at Columbia University. He is a member of the Society and has had a previous article published in the August 1956 issue of THE JOURNAL.

THE ADOPTION of a universal system of measurements for engineering design and production has long occupied internationally oriented minds. A giant step towards such universal compatibility has recently been taken by the National Bureau of Standards in redefining the equivalency values of the yard, the inch, the nautical mile, the pound, and the grain in relation to the international meter and the international kilogram.

In an announcement printed in the Federal Register of July 1, 1959, the Bureau of Standards has defined the international yard as equal to 0.9144 meter, replacing the previous definition of: 1 yard = $\frac{3600}{3937}$ meter. From the new relationship, the value of the new standard inch is then derived as exactly equal to 25.4 millimeters.

The new definition for the international yard and the standard inch encompasses two basic improvements towards international and national standardization. First, the international yard will become standard by accord among the English-speaking nations, namely, the United States, Australia, Canada, New Zealand, South Africa, and the United Kingdom. Secondly, the national standard inch is now brought in to exact agreement with the industrial standard inch which has been defined since 1933 by the American Standards Association as: 1 inch = 25.4 millimeters.

The adoption of the new relationships has not gone unnoticed or unheeded by the technical and editorial fraternity. Letters and editorials have been printed, much discussion has taken place concerning the possibility and probability of taking the next, and final giant step; that of eliminating the English system entirely and embracing the metric system completely.

To add to the lively confusion, a spate of polemics on the relative merits of the two great systems usually brings forth vocal proponents of other systems, chiefly the duodecimal. These can positively and validly prove that their system of measurement alone holds the key to the cure for all industrial ills.

It can, therefore, be readily seen that to standardize or not to standardize on a universal system of

basic units and measurements is a question which recurs frequently and agitates many minds. The scientific language of the metric system has great appeal to the scientist and the scientifically oriented engineer. The English system, apparently less scientific, is being closely scrutinized for faults, flaws, and general consignment to obsolescence. Although one dare not argue with the scientific world as to the superiority of the metric system over any other, it still seems that in the practical production of the goods of civilization, the choice of dimensional systems is governed by other factors than "scientific" engineering or a driving desire for standardization.

The passion to standarize everything, to bring all things to uniform conformity, to force everything into a common mold is a strong trait of some human natures. It is impossible for these natures to accept a peaceful co-existence of two or more systems of measurements without striving fervently to eliminate all but the one system they favor or practice. They cannot at times conceive that systems of measurements that have been in force by custom, habit, and decree for many, many years need not necessarily, because of age and usage, be bad systems. To them it is standardization for standardization's sake; the goal to be attained with single-minded purpose. Standardization is not at all considered as a means towards a worthy end, as a tool for betterment, but as an end in itself. In other words, the thinking appears to be: "Two different systems of measurements? Impossible! Unscientific! Let's standardize forthwith. The reasons are self evident and obvious."

Whether the metric system of measurement is superior to the English system is a moot question which has engaged many people, engendered many arguments, and produced many facts to prove either side. Philosophically there is no reason why a metric length of rod carefully kept in Europe has any greater degree of merit as a scientific measurement base than had there been an equivalent English prototype length equally carefully kept in this country. From a historical point of view it would appear that the English system should have universally prevailed. After all, the Industrial Revolution, which brought with it mass production and carefully controlled repetitive measurements, received its greatest impetus in England and its greatest expansion in this country. By reason of historic evolution, growth, development, and intensity of usage, a trenchant argument can be offered for the universal adoption of the English system of measurement.

But the agitation, the weight of argument, and the preponderance of appeal appear to be all in the other direction. The metric system is superior! It is European, it is not native, it is, therefore, scientific. It must be universally adopted before the whole world perishes in a holocaust of clashing measurements.

Those who are imbued with, adept at, and accustomed to the metric system tend to ignore the millions of dollars invested in tools, measuring instruments, drawings which are the backbone of our nation's productiveness. They seem to forget the hundreds of thousands of engineers, draftsmen, mechanics, inspectors, students who have been trained, are experienced and possess infinite facility with the use of these items. They would scrap all inspection procedures and devices, all gages, jigs, fixtures which retain the barbarous stamp of the English system.

They would change everything, no matter what the cost, the disruptions, the dislocation, the retraining required. They consider that change is good, the metric system is good. Convert, therefore, to the metric system. The world will be saved thereby; the universe will not perish!

If we change to the metric system of dimensioning, should we not also adopt the international metric standards for tolerances, allowances, and fits? Will not all our screw threads, gears, prefabricated parts, items such as piping, tubing, valves, and fittings change to metric standard sizes? Must we not retrain everyone into the use of first angle projection for drawings since this is the prevalent projection in metric drawings?

As a matter of fact, why stop at universalization of measurements? Materials are of vital importance in design. Should materials specifications not also be made universal so that they will be identical no matter what part of the world produces them?

The conversion costs cannot be lightly disregarded, the problems will be tremendous, the gains may be ephemeral, the losses could take years to recoup.

It is not, of course, intended to denigrate the metric system of measurements, or even to imply that this system is basically inferior to the English system. In fact, the author, having worked for a number of years during World War II on conversion of metric drawings, primarily German and French, to English language standards and units, found a certain classic simplicity in the system of dimensioning which could not be approached by the clumsy fractional dimensions of the English drawing. Interestingly enough some of this simplicity would give deep satisfaction to the most *avantgarde* of functional drafting advocates. Such items as omission of cross hatching and elimination of arrow heads were evident in drawings of the pre-World War II era.

It is possible, therefore, that the big pressure for adoption of the metric system as far as plan work is concerned really revolves about certain superior aspects which the metric dimension embodies.

The metric dimension whose basic unit is the millimeter is a simple whole number. It is clear, neat, not easily mistaken for anything but what it is —a dimension number. It dovetails readily with the newer concepts of functional drafting by streamlin-

ing dimensioning and assuring clarity if reduced size prints are used for production work. It is a single line figure which, unlike the English system, does not trail after it a fractional dividing line exhibiting upper and lower figures in various gymnastic altitudes and conditions of crowding.

Dimension sizes are readily added, subtracted, divided, or multiplied with minimum chances for error in arithmetic or interpretation. There is also a direct and appealing relationship between the decimal scale of the metric system and the anatomical scale of our ten toes and ten fingers. This helps us, even in our dullest moments, to calculate unerringly and swiftly the dimensions of the most complicated configurations.

It is this simplicity of dimensioning which appears to give the metric system its greatest advantage and which, one suspects, generates its greatest appeal to the scientifically minded segment of the technical community.

If this is the case, however, that the underlying reason for advocating the adoption of the metric system in industry lies in the neatness, clarity, and simplicity of dimensioning, then there is no reason for abandoning the English system at all. It is merely a matter of eliminating the fractional system of dimensioning and applying the best features of metric dimension to the English drawing.

In this manner, the advantages of the metric type of number would be obtained but none of the English units, gauges, tools, instruments would need to be abandoned, made obsolete, altered, or recalibrated.

There is actually nothing novel in the use of single numbers and decimal dimensions in the English drawing system. This can be readily shown by the many years usage and standard practice of dimensioning civil engineering, surveying, and map drawings in feet and decimals of feet. In mechanical drawings it has been standard practice with some companies and it is so recognized by the American Drafting Standard Manual for drawings, as an alternate procedure to fractional dimensioning, to use inches and decimal of inches to two places for non-critical dimensions. This certainly simplifies the drawing and gives it a metric appearance and neatness. It does require familiarity with the decimal scales and carries with it the classical danger of misplaced decimal points. There is, however. still another possibility which gives an English drawing the nearest approach to and appearance of a metric drawing.

Curiously enough the author came across this possibility in the course of attempting, with consistent failure, to translate and transpose some Greek drawings to English units. These drawings appeared to be metric. The whole numbers of the millimeter unit were evident everywhere, but somehow dimensions would just not jibe; correlation could not be obtained. It was finally discovered that the basic unit was English; that this unit was 1/64 inch. Thus a dimension of 1 inch was 64, 10 inches were 640, 1½ inch were 96, and so forth.

The system proved very neat, consistent, and simple to apply. It did not abandon the well tried and true English system; it merely used the 1/64 inch as the basic unit of measurement rather than the millimeter, or the decimal point. It gathered all the advantages of the metric system without the disadvanages engendered by discarding the basic English system. It retained the basic tools. instruments, and measuring devices of the English system, but did not reject the inch and decimal of an inch for closely controlled measurements. In this respect, therefore, it was not inconsistent with existing standards of decimal tolerances and allowances. The drawings looked, worked, and checked as if metric, but were actually English to the core—which was indeed to their great credit.

There is nothing revolutionary about using a part of an inch as a unit of measurement or identification. As one example, in the vast field of tubing sizes, certain companies identify their various tube diameters by whole numbers representing a multiple of 1/16 inch. Thus a ½ inch diameter tube if listed as No. 8, and so forth.

The 1/64 inch as a basic unit has the advantage over the millimeter in being the smallest unit size that can be comfortably distinguished on an ordinary scale without magnification or vernier attachments. It, therefore, lends itself more readily to the field of modern closely controlled dimensioning than the much coarser millimeter unit. It is also superior to the decimal .01 inch since the .01 inch is too fine a dimension for the average naked eye. It is, in other words, a good practical measurement compromise between the too large millimeter scale and the too small decimal inch scale. Furthermore, close tolerances can still be depicted on drawings as decimal parts of an inch since the inch is still the ultimate base of measurement.

Therefore, no micrometer, vernier caliper, or other milli- or micro-inch measuring device need be scrapped as a sacrifice to a new system of measurement. Fundamentally, the 1/64 inch base of dimensioning proposed a simpler notation for the English system, and not a new unit of measurement.

Objections might be raised that the use of the 1/64 inch unit for large dimensions would lead to astronomical figures and calculations. It can be pointed out that industry adapts itself best to the system it needs and finds practical. Where smaller dimensions predominate, they can be expressed in multiples of 1/64 units. Large dimensions such as might obtain for ship compartment layouts or machinery arrangements could be denoted by inches and multiples of 1/64 units. Thus, $10'\text{-}1\frac{33}{64}''$ would appear on the drawing as 121"-33. On the other hand, very large dimensions used in mapping or ships overall

dimensions and offsets might best be represented by feet and decimals of feet.

In all cases, industry should be reasonably free to determine its choice and not be bound in a straight-jacket of rigid standardization. In this respect it is interesting to note that the Bureau of Standard's redefinition of the yard does not presently affect the field of geodetic surveys. The foot, used for this purpose is referred to as the U.S. Survey foot and is still defined as in 1893 as 1 foot$=\frac{1200}{3937}$ meter, "until such a time as it becomes desirable and expedient to readjust the basic geodetic survey networks in the United States after which the ratio of a yard, equal to 0.9144 meter shall apply."

Serious attention might be paid to finding an appropriate name for the 1/64 inch unit. A resounding name replete with scientific aura and intent such as Mach or Angstrom might go far towards making this unit palatable to the expert engineer, the scientific engineer, the pedagogical engineer. Once accepted by this higher stratum of technological society, it presumably would be adopted with little question or hesitation by the ordinary engineer, designer, draftsman, and shop worker—in short, by all those in the direct firing line of production work.

Reviewing the entire field of metric versus English dimensioning, there can be no particular reason why both systems cannot coexist successfully as heretofore. The English system can be improved by eliminating the fractional dimension and changing to one of the simpler systems of notation. Each system can be used as best adapted to the needs of the particular industry. In addition a measure of self-protection may be afforded on the military side by retaining aspects of duality in industry. Variations of railroad gauge width in certain countries are illustrative of such possible precaution.

It would be a dull world, indeed, if we internationalized and standardized everything. Customs, habits, language, clothing, even the calendar and railway gauge widths, would be subdued and submerged into one dreary gray monolith of uniformity. In our present struggle against blind conformity, such an ultimate fate should be unthinkable.

With the increasing popularity of Kort nozzle installations on tug boats, the adoption of this propulsion device has attracted interest for installation on fishing vessels, particularly trawlers. In a paper presented before the Second World Fishing Boat Congress in Rome, J. D. von Manen, G. Vossers, and H. Rijken described a series of tests conducted at the Netherlands Ship Model Basin which made a direct comparison between a typical trawler model with a conventional propeller and one equipped with a nozzle propeller. The tests indicated that the nozzle increases the pull considerably for ships trawling in following and quartering seas. For trawling in ahead seas, the nozzle causes a decrease in speed and pull at constant shp. For free route, the nozzle propeller required a higher shp at a lower rpm in still water and in following and quartering seas. In ahead seas, the difference between the two propellers is small for the free route condition. Also, the influence of the nozzle propeller on the amplitude of pitch and heave, and other indicators of seaworthiness were observed and discussed in the paper which is entitled "Tests with Trawler Model in Waves."

COMMANDER BERNARD M. KASSELL, USN

MARINE ENGINEERING NOTES FROM THE SOVIET PRESS

THE AUTHOR

enlisted in the Navy in 1931, and has served continuously since that time. He attended Cornell University and Maryland University, obtaining his B.S. degree in Military Science from the latter institution. He has had a wide range of duty assignments, including tours as Engineer Officer and Repair Officer on various ships and tenders. He was recently stationed in Casablanca, Morocco as Commanding Officer, Military Sea Transport Service Office, Morocco. He is now on duty in the Office of the Chief of Naval Operations.

THE RECENT debates and hearings on the national defense posture have served to alert even the least interested among the citizenry to the fact that there are differences of opinion, even among the experts, as to the type of weapons-mix we should have for the near future. All too often, however, we forget that merchant ships are an integral part of that mix, for it is the merchant ship, and it alone, which can carry on the peacetime activity of trading, and, at the same time, be standing by for use as needed during war. It must be recognized that, in the event of an all-out nuclear war, the merchant ships scattered all over the globe will probably be the chief means of transportation remaining capable of use to start the rehabilitation of a devastated world.

We are not in very good shape at the present time in the realm of shipbuilding and shipping. For what it is worth, comfort-wise, we are not alone.

The shipbuilding industry, throughout the world, with minor exceptions, is sick. Orders for new ships have been falling steadily for the past two and a half years and the 8.7 million gross tons of shipping launched in 1959 was the first decrease since 1947, indicative of the fact that the peak has been reached and that the downhill slide has started. True, there are millions of tons on the ways, but when this construction is completed—what?

The reasons for the changing picture are many, and varied, but the illness has merely served to expand the search for a cure; a cure both cheap and quick in trade expansion. This is the cure advanced by the Soviet Union, of course.

There is, unfortunately, a hard core of truth to certain of the claims advanced by the salesmen from the Soviet Union. Disregarding the real purchasing power of the ruble, we note that the foreign trade of the Soviet Union has increased from 13 billion rubles in 1950 to 41.7 billions in 1959. Of this 1959

figure, 10.4 billion, roughly 25 per cent, is credited to trade with 60 capitalist nations, and more is promised.

All this makes for a fine selling point in many areas and provides the USSR's Foreign Trade Minister, Nikolay S. Patolichev, with an opportunity to point out that American business men have recently indicated that they would like to see trade between the two nations expanded, but that our government seeks to "go against the current" and to counteract any improvement in commercial and economic relations with the Soviet Union.

At this distance from the bargaining table everything looks favorable, but it is a known fact that the goal of the Soviet Union is to provide herself with a merchant marine which will be capable of handling 100% of her foreign trade, and, since she has a virtual monopoly in coastal trade, wherein lie the benefits? If one gains in the manufacturing area, one loses in the shipping area. And only increased shipping can call for increased shipbuilding.

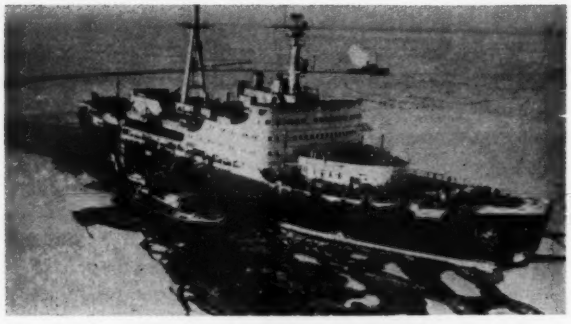
It is obvious that depressed shipping markets will, if played correctly, provide the Soviet Union with advantageous charters as needed during the build up of tonnage under the Hammer and Sickle, and advantageous charters merely mean that the selling price of a commodity can be lower than that of a competitor who must pay higher shipping charges. This is the case in many areas today. We are engaged in a trade war which, because of its very silence, is that much more deadly.

There is no ready solution to the problem, for not all the factors are available. Enough of the factors are, however, available to make it self evident that marine engineers and naval architects are facing a serious problem and are challenged to come up with new ideas and new innovations in order to keep our own industries—shipbuilding and shipping—strong and viable.

ATOMIC ICEBREAKER *Lenin*

Although *Lenin* was commissioned in September, 1959, and was in the Baltic Sea on trials later in that year, little has been heard of her since early 1960. The big icebreaker stood out on the Neva River, in the Leningrad area on 15 September and, on the 20th, reported that the first tests had been completed. These tests appear to have been preliminary operating tests of the reactors, the main turbogenerators and the drive motors. She also loaded black oil while on the Neva and was, in October, visited by members of the United States delegation which was in the Soviet Union at that time. By 17 October she reported from the Baltic Sea that her trials were progressing successfully and that her reactors were capable of providing power to a city of half a million population.

Lenin is equipped with three, individually operated, nuclear reactors of the pressurized water



The atomic icebreaker *Lenin*.

type, one of which is reversible. The reactors are installed in steel drums, welded into a special containment vessel made of stainless steel. Two control posts, the main, and a reserve, are available. The steam generating installation consists of three independent sections. Each of the single-flow turbines is rated at 11,000 hp and turns two double-armature direct current generators through reduction gearing. The current produced by the eight generators is supplied to the three main drive motors. The amidships motor takes half the total power, with each of the two wing motors taking half of the remainder. The drive motors are cooled by a closed air system equipped with coolers. The amidships motor is rated at 9,800 hp; each of the wing motors at 4,900 hp. Radioactive water can be discharged, if necessary, into shielded tanks and two systems of dosage control are used, one technical, the other biological.

The hull is divided into compartments by 11 main, transverse bulkheads, and it is claimed that any two can flood without danger of the ship sinking. The ice protection plating on the hull is 1.44″ thick amidships, 2″ thick at the bow, and 1.76″ thick at the stern. Heeling tanks are serviced by electric pumps which can handle 4,000 tons per hour. *Lenin* is constructed with four decks and two platforms and will carry a helicopter while operating. The landing area, as well as the hangar, is aft, as is a 40-ton towing winch.

Two radars for long and short ranges, as well as other navigational equipment is, or will be, installed and the radio equipment is sufficient to cover all operating frequencies, including those used for ship-to-shore and ship-to-air.

By early November the Murmansk Steamship Company, which will control the icebreaker, received word that the ship was getting ready for "an impending Arctic voyage." On 5 December it was further announced that the *Lenin* was to be placed in "experimental" operation in honor of Constitution Day and, on 22 December, the 250th anniversary of the founding of the building yard, *Lenin* was placed in service with the merchant fleet as an active unit. The trials had covered over 2,000 miles

and the reactors and the main turbo-generators had operated over 1,000 hours. Little else has been heard of her since. *Lenin* could, of course, be operating in the Leningrad area, assisting shipping there; or she could be undergoing post-trial repairs or alterations; or she may have run into troubles.

The time and money spent on the construction of *Lenin* has resulted in the construction of the first operational nuclear merchant-type ship, a feat which, in today's propaganda-conscious world, is of great moment. But above this, is the hope on the part of planners in the Soviet Union that *Lenin* will have the power and the durability to do just one thing—keep the Northern Sea Route open for longer periods of time each year. It can only be speculated that successful completion of the trials had something to do with a TASS announcement, early in March, that the Arctic fleet was being reinforced and that additional research stations were being set up in the northern polar regions Two new expeditions will operate in the Arctic in 1960 and once again we are told that the Northern Sea Route will become a "great traffic lane in the next seven years."

This, naturally, remains to be seen, for the Northern Sea Route has been reluctant to surrender to the planners and, despite the icebreakers built in the Soviet Union in the 1930's, despite those acquired from Finland, despite every effort, operations come to an end, usually in the early fall of the year, when the young ice forms. Huge sums of money have been spent on repairs to ships which have suffered damage from the ice, equally huge sums have gone into research and development, all for the development of a closed passage from Europe to Asia. A. Sokolov, who heads a sector in the Ice Forecasting Division of the Arctic-Antarctic Scientific-Research Institute, puts it this way: "The atomic icebreaker, thanks to its strength, is considered able to cope with the Arctic ice. Consequently transport ships can leave the Arctic seas at a later date than ordinarily; this, in turn, will permit the making of additional deliveries to Arctic points and also permit the ships to bring out thousands of tons of additional cargo."

These hopes are riding on the following characteristics of *Lenin*:

Length overall, feet	440
Beam, feet	90.5
Height of side, amidships, feet	53
Draft, feet	30
Displacement, tons	16,000
Horsepower, shaft	44,000
Endurance	One year
Horsepower/displacement ratio	2.75/1
Propellers	3
Maximum speed, full displacement, open water, knots	18
Steady speed in ice 7'10" thick, knots	2
RPM at maximum speed for amidships and wing propellers	185/205
Propeller thrust developed in ahead direction during dock trials, tons	330
Total weight of the nuclear installation, including shielding, tons	3017
Weight of the machinery installation, including main drive motors and electrical station, but without the nuclear installation, tons	2750
Total steam productivity, tons per hour	360
Steam consumption in the main turbo-generators, tons per hour	204
Steam productivity of the auxiliary steam boiler, tons per hour	10
Power of the auxiliary electrical stations, kw	6200

SOVIET-FINNISH TRADE AGREEMENT

The Soviet-Finnish Trade Agreement, negotiated in October 1959 as an extension to the Agreement concluded in 1954, has been ratified by both nations, with the result that the Soviet Union will continue to receive important additions to the nation's merchant marine. The new Agreement covers the period 1961 through 1965 and has two interesting innovations.

The Soviet Union has agreed to pay for part of the deliveries in free currencies in an amount not in excess of 40 million rubles annually for the term of the Agreement. While the rate of exchange is not stipulated, it is agreed that if the gold content of the ruble, presently established at 0.222168 grams of fine gold, changes at any time, certain adjustments in the international accounts will take place.

The ship list is interesting, as may be seen from the following list:

Type Ship	*Number*
Icebreaker, 22,000 horsepower	2*
Motorship, dry cargo, 11,000-13,000 tons	20
Timber carrier, diesel, 3,000-3,500 tons	36
Tug, salvage, 1,700 horsepower	7
Tanker, seagoing, 4,000-4,500 tons	25
Motorship, cargo, lake-type, 1,000 tons	20
Lightship	2
Barracks ship	8
Cable ship	2

* One icebreaker from the previous Agreement (probably *Leningrad*).

As part of the Agreement, the Soviet Union will deliver to Finland somewhere between 8 and 10.5 million rubles worth of marine equipment annually, as well as between 125 and 165 million rubles worth of petroluem and petroleum products. In return, Finland has agreed to provide 5 million rubles worth of spare parts for the ships (built or building is not stated) and will do 10 million rubles worth of ship repairs.

The Soviet Union had previously ordered 12 of the tankers which now have been increased to 25 over the five-year period stipulated. The salvage tugs previously ordered were rated at 1,000-1,200 horsepower, as opposed to the more powerful ones one the new list.

There is little question that deliveries by Finland will help the Soviet Union in its economic drive, as well as to push the country along the path to self-

sufficiency in tonnage to handle the foreign commerce which is now assuming ever-increasing importance in the planners announcements.

SHIPS ORDERED IN POLAND

In addition to the publication of the Soviet-Finnish Trade Agreement, the publicists for TASS, the Soviet Union's news agency, released word, early in the year, of an order placed in Poland for the period 1961-1965 for 122 merchant ships. According to the report, this is the largest order ever given to Polish shipyards.

These deliveries will further increase the capability of the Soviet Union to handle her commerce. Just how extensive is this trade? Ships assigned to the Black Sea Steamship Company, in 1959, were said to have covered a distance equal to 350 times around the world at the equator. These same ships delivered export cargoes to over 200 ports in 36 countries of the world. Many of these deliveries took place on regularly scheduled lines operating out of the Black Sea to ports in Albania, Bulgaria, the United Arab Republic, Italy, and India. During the course of 1960 shipments will increase to various of the countries, including Japan, and tankers will move petroleum products to Mexico for the first time. Marked for increase as well are Iraq, Tunis, Morocco and India.

On the Baltic side of the Soviet Union the Latvian Steamship Company is moving cement to foreign markets for the first time, particularly to the new Republic of Guinia. Drilling equipment is moving to Latin America. The Baltic Steamship Company will open two new cargo runs this year, as well as a cargo-passenger run, all in addition to the five which had been active in 1959. Best indication of the scope of the trade is the report by the Chief of the Baltic Steamship Company, who stated that his ships had increased their take in foreign exchange 54 per cent in the past three years. His company operates 25 per cent of its ships on regular cargo lines, including runs to the Arctic, and the carriage of timber in the coastal trade.

THE "HYDROSTAT"

"Hydrostat" is the name which has been given to a steel chamber which is being built in Leningrad on a design prepared by the State Design Institute for the Fishing Fleet. It is becoming increasingly curious to this observer that most of the devices which have any use for research in such fields as oceanography, hydrography, and anti-submarine warfare are either developed—in the Soviet Union—or built by, or for, the fishing industry. For example, one trawler and a medium sized refrigerator-trawler had, early in January, already spent over four months in the South Pacific "surveying new fishing grounds." The two ships belong to the Main Administration for the Fishing Industry of the Far East. Mackerel were found in the South China Sea in sufficient quantity to require the outfitting of an expedition to fish the area. The same Main Administration already has, or will, in 1960, send out several large expeditions to "outlying fishing grounds." Ships are to start fishing the Yellow Sea. Last year a scientific-research vessel found ruff, a perch-like fish, in the northeastern Pacific area and trawlers were to be sent to that area. Efforts along the African coast have been of a similar nature. Mention has been made in these pages already of the *Severyanka,* a Soviet Navy submarine refitted for scientific research work, said to have used her torpedo tubes to carry fresh water and provisions, and which made several excursions before dropping out of print.

All of which brings us back to the "hydrostat," for it is designed to probe far deeper than Soviet man has thus far gone, even in *Severyanka.* When completed, the radio-tube shaped chamber will be turned over to the Polar Scientific-Research Institute for Marine Fishing and Oceanography. The chamber, displacing 2½ tons, will be equipped with various instruments, including movie and still cameras. In an emergency the lone observer can release the cable connecting the "hydrostat" to the ship on the surface and, by releasing ballast, surface independently. Tests have already been carried out in a special chamber full of water and, using special pumps, a pressure of 75 atmospheres, equivalent to a depth of some 2,500 feet was developed. The hull passed the test successfully and completion may be expected shortly.

GAS-TURBINE EQUIPPED TANKER PLANNED

The Ministry of the Maritime Fleet some time ago requested that the State Committee for Shipbuilding provide it with plans for a 20,000 ton capacity tanker with a gas-turbine propulsion installation. The Committee's Design Bureau was assigned to the job and has provided the Ministry's Technical Council with the needed drawings and specifications. This project is now, apparently, under review, and it is suggested that ships of this class be built in the Admiralty Shipyard, in Leningrad.

This tanker class, which, it seems, is to be both gas and diesel propelled, will have the following characteristics:

Length between perpendiculars, feet	550
Beam, greatest, feet	75
Height of side, amidships, feet	39
Draft, feet	30
Coefficient of form	.784
Displacement, full, tons	26,790
Tank capacity, cubic feet	960,000
Speed, planned, knots	17.1
Horsepower, maximum	13,000
Cruising radius, miles	10,000

The tanker will be able to carry four grades of petroleum products at the same time; loading for gasoline will be 17,200 tons, while class two or class

three products will be 17,600 tons. By the use of automation it is planned that crews can be cut to 33 men, 20 to 25 per cent less than the number carried on similar sized tankers. Tank cleaning is to be done by use of a closed system employing chemicals and hot water which will be heated by steam from a boiler capable of producing 24 to 30 tons of steam per hour. Unloading will take from 10 to 12 hours; tank cleaning 2 to 3 days.

The gas turbine is to be of the open type, two units transmitting power to the propeller through a dual, two-stage reduction gear. Rated power for the gas-turbine installation is to be 11,800 horsepower, with a figure of 13,000 cited as maximum.

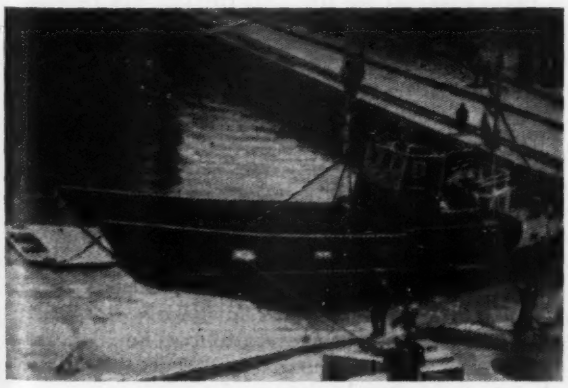
The same hull will also carry a diesel installation, of unspecified size and make. The Black Sea Steamship Company has been designated as future operators of the class and is assigned the job of training crews to handle the gas-turbine installation.

NEW CLASSES OF LANDING BARGES

Many unloading points in the Arctic, and elsewhere, are without cargo handling facilities of any description, so that the cargo ships operating to these points must carry their own barges and small tug cutters in order to get the cargo ashore. The types of "floating stock" supplied until now have been extremely unsatisfactory, since, because they have proven to be clumsy and slow, the unloading usually has taken longer than planned and demurrage has been high.

The Central Planning-Design Bureau No. 7 worked out the design for a landing barge with a bow door, or gate, basing its work on a prototype which is simply designated as type "A". The first of a series built to the new specifications has been named *Sevyer* (see cut) and is 1.6 tons lighter than the prototype. Its empty weight of 15.3 tons can be handled by a 15-ton Soviet cargo boom. *Sevyer* will carry 14 tons, but was tested in May 1959 with a 13-ton pay load.

In force 2 seas, and with a force 5 wind blowing, the barge made 7.45 knots with the 3D6S engine turning up 1,450 rpm. Landing tests were made using the S-80 tractor and special containers on runners so that skidding off the barge was simplified. Draft for the landing was 2′4″ forward and 3′ aft. The only difficulty encountered appears to have been a familiar one to amphibious personnel—keeping the barge from broaching.



Landing barge of the *Sevyer*-class.

Quantity production is suggested. What is not mentioned, however, is the experience which merchant seamen will gain in making landings using a type of craft closely resembling a standard, small, landing craft suitable for use in amphibious operations.

In contrast to the relatively small *Sevyer*, another type, known as *SMB-1*, (see cut) is in service. The initials are for "Self-propelled Maritime Barge," a type designed for carrying building materials which cannot be damaged by water. It too is designed to operate to areas without fixed installations and to put its bow on the beach, loading and discharging over a hinged ramp in the bow.

Self-propelled maritime barge, *SMB-1*.

SMB-1 is certified for use at distances of 20 miles to seaward and can, within that radius of action operate between ports which are 50 miles apart.

The characteristics of *SMB-1* include:

Length, greatest, feet	158
Beam, feet	21½
Height of side, amidships, feet	8½
Draft, mean, full load, feet	6½
Gross Registered Tons	200
Volume of cargo hold, cubic feet	9,500
Speed, knots	10½

The hull is of all-welded steel and has an open cargo hold which is 74′ x 13′, a double bottom and what are nominally termed as longitudinal and transverse bulkheads. The bottoms are made up of nine tanks and the wings contain the storerooms of various types. Twin rudders and a stern anchor are fitted.

The propulsion installation consists of two 12-cylinder diesel engines Mark 3D12, each of which is rated at 300 hp at 150 rpm. Starting and operation is accomplished from the wheelhouse by remote engine controls. Fuel supply is limited to 2.8 tons, enough for about 24 hours of continuous operation at full speed.

Power supply is from a 12-kw alternating current generator, feeding a 220-volt network for

power and, through a step-down transformer, the 24-volt lighting system. A shaft generator type G-732 operates off one main engine when the craft is underway, providing 24 volts, direct current, for lighting. At anchor the standing lights are battery fed. A small, coal-fired boiler is installed to provide heat and hot water.

WHALER BASE *Sovetskaya Ukraina*

The whaler base *Sovetskaya Ukraina*, built in the I. I. Nosenko Shipyard in Nikolayev, and now operating in the Antarctic, is equipped with two, two-stroke, crosshead type, solid injection, single-acting, reversible diesel engines built in the Burmeister-Wain Works in Denmark.

The Type 74-V TBF-160 engine is a modification of the non-supercharged engine which the firm has been building since 1939. The present model employs turbine supercharging and the first engines of this model were installed in *Doris Maersk* in 1953.

A 6-cylinder version which developed 5,520 ehp at 115 rpm was used to engine the two tankers built in Denmark some years ago for the Soviet Union. *Apsheron* is rendering excellent service, from all reports, but *Tuapse*, the sister ship, was seized by the Chinese Nationalists in June 1954, and is, it is assumed, still in their possession in the Taiwan area.

The engine installed in the whaler base, and which, it is assumed, will also engine the other bases now building, develops 7,500 ehp at 115 rpm. The weight is 95 pounds per ehp and fuel consumption is on the order of 6 ounces of diesel fuel per ehp per hour.

This same engine, but in a 7-cylinder version, has passed through the design stage and may be built in one of the engine building plants in the Soviet Union as the propulsion installation for the dry-cargo motorships in the 10,000-ton deadweight class building in the Soviet Union.

When the new whaler base sailed from Odessa on 17 October 1959 enroute to the Antarctic she had in company eight new diesel-electric propelled whale catchers, all built in the I. I. Nosenko Shipyard. The new group brings to 16 the number of new whale catchers in operation. Since there are additional whaler bases coming along, each of which is to have its own fleet of these modern catchers, the building program for the catchers will be a rather extensive one indeed, numbering perhaps 48 more over the next three years. Descriptive data on the whale catchers appears in the "Notes" published in the "Journal" of November 1957.

FISHING FLEET CONSTRUCTION

Minister A. A. Ishkov, of the Gosplan of the USSR, has announced that, by 1965 the fishing fleets of the Soviet Union will have to increase their catch from the 3.2 million short tons of 1958 to 5.1 million short tons. Eighty per cent of this catch is to come from the open seas and oceans. The increased catch is needed to assist in feeding an expanding population, but, at the same time, removal of fishing craft from the traditionally heavily fished inland and coastal waters will assist materially in restoring and increasing depleted stocks of fish in those waters.

In order to accomplish this the fishing fleets will be provided, over the Seven-Year Plan period, with more than 14,000 new ships of all kinds. One class is that of the factory type, *Mayakovskiy*, described in the "Journal" of November 1959. The *Tropik* class, of 1,300 hp, will be built for the sardine and tuna fishermen, and will have an endurance of 60 days. Medium fishing trawlers, the *SRT* class, are to be replaced by an *Okean* class, which will be larger, faster and more powerful.

There is however, some uncertainty as to how far the builders will go with each of the classes. For example, already there are complaints about the *Mayakovskiy* class, including one which makes the flat statement that trawlers of this type are unsuited for sardine fishing along the African coast, at least. It is pointed out that sardines, even when frozen, cannot be kept in the holds for long periods of time. Unless they are canned, or processed into fish meal at once, they become bitter to the taste. The present class cannot do either. It is, therefore, suggested that what is needed for sardine fishing in the Atlantic is a diesel-electric trawler displacing at least 8,000 tons. A vessel of this size would be large enough to accomodate the canning and processing equipment, as well as to provide adequate living space for the crew.

Perhaps in an effort to satisfy the operators, planners now say that the use of refrigeration will be expanded and that fish will be fast-frozen at temperatures of between 20 and 30 degrees below zero F. Features such as this are going into 125 refrigerator ships, 68 of which will be used for processing, the remainder for transporting the fish. The transporters are to be large and fast, able to carry about 3,000 tons in the holds.

Plans also call for the construction, not necessarily in the Soviet Union, it should be noted, of 26 floating bases displacing from 15,000 to 18,000 tons, equipped with machine shops which will be able to make emergency repairs to the smaller ships assigned to each base. Floating crab canneries, able to process 1,400 to 1,800 cases of canned fish a day are on delivery plans, and these canneries will also be equipped to process waste products into fish meal.

We have already mentioned the fact that the whaler base *Sovetskaya Ukraina* is in service, the first of four already identified. *Yuriy Dolgorukiy* is scheduled for 1960 delivery, *Sovetskaya Rossiya* for 1961 and *Sovetskiy Soyuz* to follow. Each of these is to have its own group of catchers, the diesel-electric type already discussed.

Research vessels will continue to accompany the whalers on their expeditions and special types will be built for this work, equipped with modern instruments and installations. One such vessel, *Kazan,* is said to have found a new sardine area in the equatorial area of the Atlantic which is now providing rich catches of sardines, mackerel, tuna and other types of fish for ships coming from Kaliningrad on the Baltic and Kherson in the Black Sea.

There are overtones to all this fishing activity, overtones with strategic and military implications. Obviously, a research vessel worthy of the name cannot help but bring back data which will materially assist the submarine effort of the naval strategists. At the same time, there is a curious sound to such statements as "discovery of a new fishing area." Perhaps discovery in this sense does not mean the staking out of a prior claim to a high seas area, but there is nothing on the record which permits one to discard this thought. We might do well to ponder these points and perhaps look into extending our own high seas hydrographic and research efforts just in case.

NEW PASSENGER CLASS

The first of a new series of passenger ships for use in both the Black and Caspian seas, *Kirgizstan,* is scheduled for operations this year in the Caspian. Built in the A. Zhdanov Shipyard, on the Baltic, the 4,000-hp motorship carried out underway trials in November 1959. Two sisters, *Moldaviya* and *Svanetiya,* are scheduled for delivery this year.

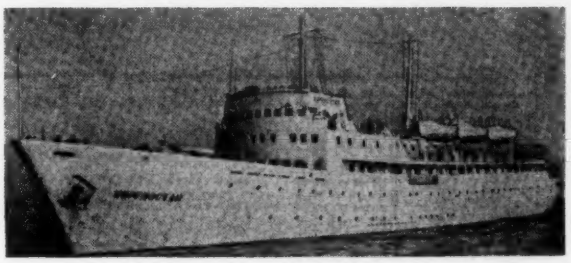
The class is designed to operate as both a river and a sea-going type, and is a twin-screw, three-decked ship with a raked bow and a cruiser stern. Some characteristics follow:

Length overall, feet	332
Length at cargo waterline at draft of 11.8′, feet	308
Beam, greatest, feet	48
Draft at full load, feet	12.3
Draft for shallow approaches, feet	11.8
Height of side, amidships, to main deck, feet	18.7
Displacement at full load, tons	2960
Displacement at draft of 11.8′, feet	2750
Deadweight, cargo, tons	576
Main propulsion, 8DR 43/61 diesels, hp	2x2000
Speed, knots	16
Cruising radius, miles	1200
Passenger capacity	250
Crew	76

On the Caspian Sea the class will operate between Astrakhan and Baku and Krasnovodsk, while on the Black Sea the operating lines will be between Rostov on the Don River and Odessa and Batumi, with stops at intermediate points still to be determined.

The cabins will accomodate one, two and four persons and the class will feature air conditioning throughout.

With draft a limiting factor, the class has eliminated the installation of evaporators and has a fresh water capacity sufficient for five days, basing needs on 25 gallons of water per day per person on board. In order to make the ports of Astrakhan and Rostov it will be necessary to consume water, oil and fuel in sufficient quantity to make the limiting draft.



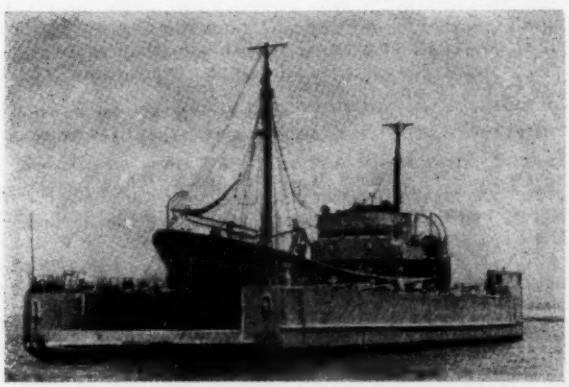
Passenger motorship *Kirgizstan.*

Classed as L-R4/1S, the class is strengthened for ice operations in other than solidly frozen areas, additional framing having been installed from the bow aft to frame 45.

TRANSPORTER DOCKS

The submarine building yards in the Gorkiy area are, as a glance at a map of the Soviet Union will show, remote from deep water. There are, evidently, certain strategic advantages to be gained from building submarines inland, away from prying eyes yet, at the same time, close to the major manufacturing areas and sources of supplies and manpower. However, building the submarine, and getting it to tidewater, are two different things.

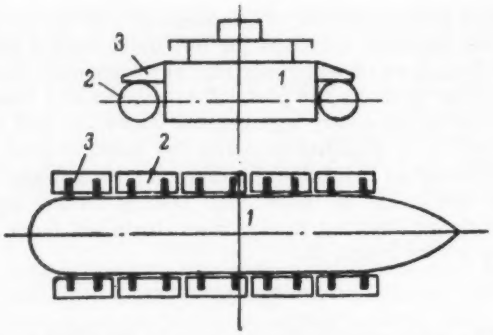
Going back several years, we find that engineers and designers have collaborated to use first, pontoons, and more recently, transporter docks to move not only submarines, but trawlers and other types of seagoing ships from inland areas to open water. According to pictorial evidence, pontoons were flooded, moved alongside the ship to be lifted, pumped out and, as they rose in the water, were secured to clips on the ship's side. The lifting effect



Transporter dock with trawler.

thus obtained was sufficient to float a 6,000-GRT ship.

Over the years this relatively crude method has been refined, but is still used as simple and cheap. With submarine hull shapes, however, it is necessary that transporter docks be used. The same is true of trawlers and other than flat bottomed vessels. About the only limitations are those imposed by water depths, size of locks, and heights of bridges above the water.



Sketch of pontoons used to lighten a ship. As shown (1) is the ship, (2) the pontoon, and (3) the clip.

New construction, be it naval or civilian, must be moved to open water to be tested underway and accepted by the various trial commissions and acceptance commissions. Since the trip down the river is made in a dock, the ship concerned need not be fully equipped, or even manned. Consequently, the load is as light as possible. Accomodations are kept to a minimum, and auxiliaries for the dock too are minimal. In fact, one dock (see cut) used to carry trawlers gets its lighting from the tug, and has only one portable gasoline driven handy-billy for fire fighting purposes. Its four man crew, made up of a dockmaster, an artificer and two seamen, is housed in one four-bunk cabin aft.

This dock has the following characteristics:

Length overall, feet	164.0
Length between sills, feet	157.0
Beam, greatest, feet	47.5
Beam, wall to wall, feet	32.8
Height of side, amidships, feet	15.0
Height from bottom to superstructure, feet	20.0
Displacement, empty, tons	173
Displacement with trawler, tons	533
Mean draft, empty, feet	.95
Draft, with trawler, feet	
Forward	2.2
Aft	3.5
Mean	2.9
Capacity of ballast tanks, cubic feet	35300

A dock of this type, although similar to class "O" ships in strength, may not venture out of the lakes or reservoirs in over force 6 seas because of danger to the trawler it carries.

In the European part of the Soviet Union the length of transporter docks may not exceed 362 feet; widths of such docks are limited by a requirement established by the Ministry for the River Fleet that a distance of some 2 feet must be maintained between lock walls and the dock's side. In individual cases, however, this requirement has been reduced to about 14 inches.

Docks used for other than trawlers are entered from the stern and, to all appearances, resemble the LSD-type in form. They are all non-self propelled, the largest yet described being 360 feet long, 80 feet wide overall, and drawing up to 15½ feet loaded.

There are, however, certain limitations to the use of transporter docks beyond depths of water, lock sizes and heights of bridges. If, for example, only a small reduction in draft is needed, it is more profitable to use the old pontoon method, rather than to invest in a dock. The cost of towing a ship on pontoons is, however, much higher than the cost of towing a dock because more tugs are needed and there is little or no use for the pontoons on the return trip. It is, in fact, more profitable to use the dock when distances of 500 miles and more are involved.

"SHIPBUILDING AND SHIPPING RECORD"

A NEW CONCEPT IN MARINE TRANSPORT

ACKNOWLEDGMENT

This article comprises extracts from a paper presented to the Royal Institute of Naval Architects in November, 1959, by P. R. Crewe and W. J. Eggington. It is reprinted from the November 26, 1959 issue of "Shipbuilding and Shipping Record."

THE HOVERCRAFT is the first operational British project in the ground-effect machine field. Although there has, for a number of years, been a tentative searching after the principles underlying such machines, it is only now that their possibilities as commercial transport and Service craft are beginning to be developed.

Since the hovercraft is a new vehicle, the appearance of the Saunders-Roe SR-N1, a manned experimental craft, excited considerable public attention and there have been a number of descriptive articles in the press. Papers of a more technical type, on ground-effect machines, are now beginning to appear and it is to be expected that these will rapidly increase in number, especially since American interest in both the commercial and defense fields is expanding fast.

The authors of the present paper have, therefore, concentrated attention upon features about which they had something personal to say, and which they consider to be of particular significance for assessing the possibility of the hovercraft becoming important in maritime transport. These features are:

The hovercraft as a fundamentally new principle in the transport field.

The powering requirements and resistance characteristics.

The likely operating costs of hovercraft in comparison with other forms of maritime transport.

Ship wave resistance is a function of pressure acting perpendicular to the hull surface, this pressure increasing with speed. The hovercraft principle provides a means of maintaining a nearly uniform pressure on the surface of the sea beneath the craft, having a magnitude which is relatively low and independent of speed. Furthermore, there are indications that it offers very interesting possibilities regarding both seaworthiness in seas of substantial size relative to that of the craft, and pitch stabilization in critical waves.

There is no indication of an upper limit of size, provided that large power plants giving the required specific power, P/W, can be developed. Thus hovercraft of several thousand tons displacement, capable of carrying either passengers or bulk cargo, or fulfilling naval requirements should become possible within two decades.

It will be seen that whereas the specific power required to pump the air necessary for vertical lift near the ground can be considerably lower than that of a helicopter, it is none the less at present at least of the same order as that installed in a fixed wing aircraft. There are, however, design refinements in hand which should in due course permit the use of specific powers which lie in the range between aircraft and ship practice. Thus it is already possible to design "boat-hovercraft" which, from

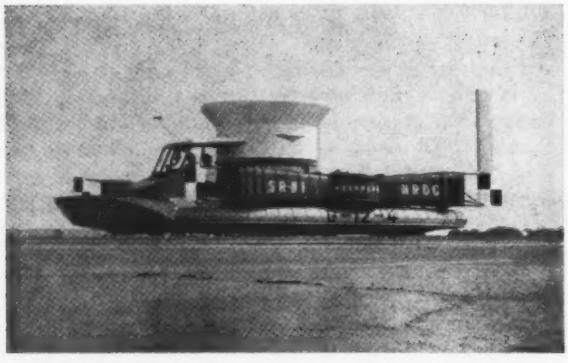


Figure 1. Moving over a concrete surface, the Hovercraft in flight.

the standpoint of economy, comfort, and convenience, offer advantages over planing boats and hydrofoil boats; while for the less immediate future "ship-hovercraft" are envisaged.

It must be emphasized that immediate engineering practicabilities are not necessarily economically attractive. The correct choice of applications having economic or naval value, at the present stage of development, is perhaps the greatest problem concerning the hovercraft at this time.

So far in this introduction the craft has been treated exclusively as a high speed boat or ship. Although, in the authors' opinion, this offers the major scope for the development of the principle as conceived by its British inventor, Mr. C. S. Cockerell, there are other concepts in which it could operate over land or amphibiously. Its amphibious capabilities would, of course, be of interest for reducing or eliminating wharves or landing stages, even in the case of quite large "ship-hovercraft." In its overland operations the hovercraft is only one of a whole category of new types of craft, generally referred to as "ground-effect machines," which are being investigated or developed in several countries.

THE HOVERCRAFT PRINCIPLE

The principle of lift used by the hovercraft is the generation of an air cushion being sensibly static, having a pressure higher than ambient and being bounded from above by the undersurface of the craft, from below by the surface over which the craft operates and at the sides by an air curtain system. Air is ejected from the undersurface of the craft through a nozzle, which extends around the whole of its perimeter, in a direction towards the center of the craft. A region of high pressure air is thus generated beneath the craft, which in turn deflects the curtain air outwards. When the cushion is established the air curtain is of circular profile touching the surface of ground or water before going to waste in the atmosphere.

Apart from being a source of air to replenish the cushion as required, the air curtain is essentially a seal that provides a pressure step between the cushion and the atmosphere. As the curtain does no real work there is considerable gain in reducing its power requirement by designing so that the energy given up to the atmosphere is a minimum. The curtain employed by the SR-N1 is a double one, *i.e.*, two simple curtains, one within the other, such that each provides a pressure step.

From the above description it can be seen that the essential components of a hovercraft are an air intake, a suitable fan driven by a power plant, a nozzle configuration, of which the most simple form is a single nozzle extending around the craft's periphery, and a substantial area of structure within the air curtain system which takes the uniform cushion load.

It has been demonstrated that in motion the air cushion travels with the hovercraft. Due to changes of pressure around the outside of the air curtain associated with the motion of the craft and cushion, the latter may become somewhat distorted but continues to perform its function. Clearly there is a limit to the speed at which the curtain/cushion system is maintained when the free stream stagnation pressure approaches the value of cushion pressure, at which condition the pressure step across the curtain at the front of the craft approaches zero.

Over water a static hovercraft displaces the surface. There is a uniform displacement under the cushion according to its pressure and a local displacement of increased depth under the curtain corresponding to its stagnation pressure. At forward speed over calm water a bow wave is generated, the surface falls away beneath the craft and a trailing wave system is generated.

It is of interest to consider how the hovercraft principle of lift is related to the principles used by existing vehicles. The most popular method is that used by land vehicles and ships, which are in contact with the earth's surface and displace it. For land vehicles operating on hard surfaces the displacement is very small of course, as for railway trains for example.

The second method of support is to give a fluid a downward acceleration as the craft moves through it. Aircraft, including helicopters, and hydrofoil craft are borne up in this manner. Hard-chine planing craft are supported by a combination of displacement and downward acceleration of water. The third method of support is to operate completely immersed in a single fluid and to maintain buoyancy by adjusting the density of the craft. This group of craft includes submarines and airships.

The hovercraft is a member of the first group, being borne up by displacement of the water or ground over which it operates. It has a feature that is unique among surface vehicles however, in that the craft does not contact the surface. Thus both water skin friction and rolling friction are eliminated at the price of the power used to maintain

the air cushion. The future of the hovercraft as a major transport vehicle depends upon how much this latter power requirement can be reduced.

CONTROL AND STABILITY

A hovercraft must be stable in heave, pitch, roll, and direction, and must be controllable in heave and direction at least. The craft rises steadily from a water surface or solid ground to its operating height and, for a given curtain momentum, there is just one height at which the craft is in equilibrium.

Tests have shown that in motion the craft remains stable in heave. The pitch and roll stability characteristics are, if anything, improved at forward speed. This is probably due to the various cross flows that may obtain in the cushion. Directional stability is, in general, mainly an aerodynamic problem, and desired behavior may be obtained by means of a suitable aerodynamic fin.

Directional control is another straight-forward problem that may be solved aerodynamically in the cruise condition and by using either the propulsion system or hydrodynamic controls at low speed. The execution of efficient turns at high speed is a more difficult problem, however, as unlike aircraft, motor cars, ships, or indeed any other type of vehicle, a side force can only be obtained at a relatively high cost in power.

Rolling the craft is not a satisfactory solution for tight turns, as only small side forces can be achieved at the cost of reduced height on the inboard side of the craft. Turns over water are more easily accomplished than over land, for any sideslip is resisted by a wave-making resistance, and this has been found a valuable aid in the case of the SR-N1.

Trimming the hovercraft, to balance changes in center of gravity position, either fore and aft or athwartships, can be achieved by controlling the curtain mass flow locally. This is not a very efficient method, as cushion cross flow results, but it is a very convenient and effective means of control. With this control, fore and aft and side thrusts are available for low speed maneuvering. The acceptable range of center of gravity position is greater than that for an aircraft but smaller than that for a ship.

Operation over rough water and uneven ground is a problem that is requiring careful study. Theoretical investigations show that while short waves and surface discontinuities can be overcome only by operating above them, waves of average length-to-height ratio can be "ridden" at cruising speed with moderate vertical accelerations and with a height that is relatively small compared with the wave height. It has been shown by experiment that as speed increases beyond a critical Froude number, which is approximately the hump wave drag condition, the response in heave can reduce to a value of some 20 per cent of wave height. The amplitude of the pitch response varies with forward speed in the same manner as heave response and can be very small at typical cruising speeds.

DESCRIPTION OF SR-N1

The SR-N1 is a purely experimental craft, intended to verify and demonstrate the cushion principle, and make research and development tests on various aspects of performance about which information and basic understanding was lacking.

The complete vehicle, together with a pilot and observer and fuel weighs just under 4 tons, and is powered by an Alvis Leonides 523/5 internal combustion aero engine which provides 435 horsepower at continuous rating. Ground speeds of 30 to 40 knots have been achieved under favorable conditions, the design speed being 25 knots in still air.

Air is drawn into an upward facing, funnel like, central intake by means of a four-bladed fan mounted directly on the engine. Two-thirds of this air is discharged through inner and outer annular slots under the craft and provides the jet curtain for the cushion. The remainder is led off to the side ducts where it is used for propulsion. The twin annular jet has aroused much interest in technical circles, and was in fact employed in connection with stability and control investigations.

Although the SR-N1 system of propulsion is most inefficient, providing a thrust of only about 500 pounds for an expenditure of some 150 shaft horsepower, it was considered to be simple and convenient for the purpose in hand, and avoided the installation of a separate propulsion engine. Thrust could have been obtained by built-in tilt in the curtain jets, as also used in Mr. Cockerell's original model, but this would have introduced an undesirable complication into the verification of the cushion principle in its basic form.

A cabin for the pilot and observer is located ahead of the intake funnel. Four detachable wheels form a beaching chassis on which the craft is maneuvered when not under power.

The basic body of the SR-N1 comprises a platform with two semi-circular ends, each of 12 foot radius, joined by a parallel portion of 6 feet in length, thus making the craft 24 feet wide by 30 feet long. The bow and the overhang of the propulsion ducts increases the overall length and width to 31 feet 5 inches by 25 feet respectively. The overall height when on the beaching chassis is 10 feet 4 inches. The effective cushion area is some 26 feet long by 20 feet wide.

Structure

High-grade light alloys were used for all the main structure, while weldable aluminum-magnesium alloys have been employed for the air intake, the propulsion ducts and smaller structural items. Flush riveting or spot welding was used on all internal ducts, stringers being placed on top of the deck,

under the buoyancy chamber top skin and beneath the buoyancy chamber. The cabin structure is of wood and the inlet guide vanes and fan of densified wood. Welded steel tubular outriggers support the fore and aft rudders.

Control System

The choice of control system was dictated by a desire to provide means which were reasonably simple, would not prejudice the demonstration of the cushion principle in its basic form, and would not involve hydrodynamic appendages since, although the latter could be efficient over water, they could not be used over land. However, the craft has considerable side and frontal area, and travels operationally at speeds ranging down to very low values at which straightforward aerodynamic control surfaces, operating in the free air stream past the craft, will provide very little moment unless their area is quite excessive. Furthermore, one of the main purposes for which the SR-N1 was constructed was to make experiments on control and stability since, like nearly all new craft, the "feel" of piloting needs to be experienced at first hand before the requirements of the control system are fully appreciated.

In these circumstances a combination of control devices was used. These comprise gate valves in the propulsion ducts, fore and aft rudders placed just ahead of and just behind the fore and aft ends respectively of the propulsion ducts, and "lift" valves located in segments of the main cushion lift air ducts.

The gate valves split the propulsion air in any desired ratio and direct it fore and aft enabling the craft to hover without forward motion, or move backwards or forwards. The propulsion jet system provided on the SR-N1 does not give assymetric thrust for directional control or lateral thrust to check sideslip, but the small rudders deflect the propulsion air and give some directional control whenever the craft is airborne, whatever its forward speed may be. The aft rudders are extended above the ducts into the free air stream, by tall, high efficiency, high aspect ratio aerodynamic surfaces, which provide directional control at speed.

Maintenance

The engine fuel and oil systems consist mainly of external tanks placed aft of the air intake funnel. These tanks are gravity filled by hand.

Large panels in both the outer and inner skin of the main air intake are detachable for engine servicing. The whole of the air intake can be removed at the rim just below the fan and the engine lifted vertically after removal of the fan and guide vanes.

Access panels to all watertight compartments are provided and drain plugs are fitted to all lower services. Nearly all the control cables are run externally for ease of inspection.

Fourteen steel shoes are fitted to hard points on the underside of the craft to allow it to be sat down when operating over land. The four beaching chassis wheels, which are buoyant, may be fitted when the craft is floating and allow it to be hauled up a slipway and to be moved around at will without applying power. Four lifting eyes are built in to the top deck and two towing eyes provided at either end. A number of walkways comprising light alloy plates sprayed with a non-slip surface are fitted on the deck for the benefit of the crew and of maintenance engineers.

PROBLEMS AND POSSIBILITIES

It was indicated in the section on "the hovercraft principle" that the main problem in the development of hovercraft is to reduce to a minimum the power requirement for the formation of the air curtains. It was shown further that since the curtain is merely a seal and does no useful work, nature gives no minimum limit to the power requirement. The performance and cost figures given in subsequent sections are based on the simple curtain which flows directly into the atmosphere. Commercial considerations prevent the publication of the results obtained from development work in this field but its importance cannot be overestimated.

Operation of the SR-N1 has demonstrated clearly that spray and dust might be problems in the civil application of hovercraft. It should be noted, however, that this problem is related to that of reducing the power absorbed by the curtain, for spray depends upon the velocity of the curtain adjacent to the water. There is ample experimental evidence to show that spray will present no problem at cruising speeds of 50 knots or more, but its elimination in the hover and low-speed conditions is being given further study.

As for operation over rough water, further work is required in this field. The use of "automatic" control may well be acceptable for the more sophisticated large passenger-carrying hovercraft. Further effort is required to ensure a comfortable and stable platform and this will involve the control of the curtain and cushion characteristics. The development of craft which are especially suitable for high-speed operation in rough water may be a fairly long-term project, but the evidence already available shows that the hovercraft has very exciting potentialities in this respect.

Trans-ocean hovercraft are expected to require at least one decade to develop. The vehicle will have to prove its worth with more modest payloads over shorter distances before serious consideration can be given to investing the capital required for developing a competitor to the oceangoing ship and the long-range jet aircraft. At a cruising speed of 125 knots the transatlantic run could be completed in just 24 hours. The lower fares that should be possible, as compared with aircraft, could have considerable passenger appeal.

JOHN A. CULVER

THE SERIES-PARALLEL TURBINE

THE AUTHOR

graduated from the Massachusetts Maritime Academy in February 1947 and went to sea on Navy and Merchant ships until October 1952. He worked for the Bureau of Ships as a Marine Engineer in the Gas Turbine and Steam Turbine Sections until July 1959. He is presently employed by the Solar Aircraft Company. Mr. Culver holds a B.S. Degree in Marine and Electrical Engineering, a commission in the U.S. Naval Reserve as Lieutenant Commander, and a Chief Engineer License in the Merchant Marine.

THE ENGINEERING personnel aboard new destroyers and some aircraft carriers are gaining experience with a different kind of propulsion steam turbine than they probably operated on their previous ships. This is called the "Series-Parallel" turbine.

BACKGROUND

The series-parallel idea is by no means a new one. It was used on 91 destroyers of the DD-251 class of World War I fame and on the USS *Raleigh* (CL-7) and USS *Detroit* (CL-8) during the early 20's. Figure 1 is a schematic of the series steam flow of the CL-7 and 8, and Figure 2 is a schematic of the parallel steam flow of the DD-251 class. As seen in Figures 1 and 2, the HP (High Pressure) and IP (Intermediate Pressure) elements have separate casings and the rotors are connected externally from each casing with a coupling. Also, the ma-

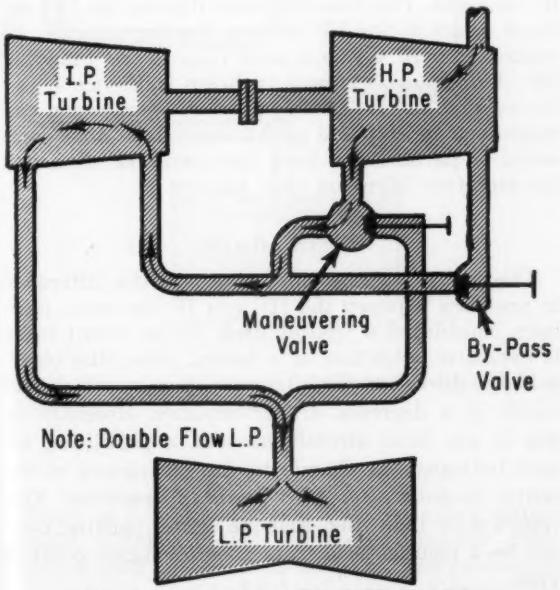


Figure 1. Series Steam Flow, CL-7 and 8.

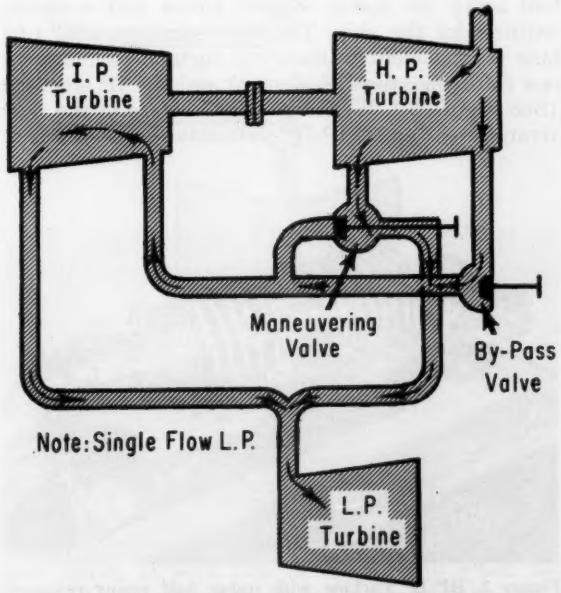


Figure 2. Parallel Steam Flow, DD-251 Class.

The USS *Forrest Sherman* (DD-931) was the first of the new destroyers to have Series-Parallel turbines.

neuvering and by-pass valves are hand operated valves. The hand valves were one of the liabilities for the series-parallel turbine because of maloperation; that is, the unit was designed for better performance than a straight through turbine but the operators did not operate the valves for the best advantage of the turbine.

DIFFERENCE IN HP UNITS

The only difference in the type of propulsion unit, as compared with other ships, is the HP (High Pressure) turbine. The low pressure turbine is generally the same as found with other propulsion units. Combatant ships have several different kinds and combinations of turbines upstream of the low pressure turbine. These combinations are selected to best serve the space, weight, power and economy required of the ship. The new series-parallel turbine arrangement utilizes two turbine elements on one rotor; i.e., the HP element and the IP element. (See Figure 3.) "Series-parallel" refers to the flow arrangement and "HP-IP" refers to the elements of the rotor. These terms are used interchangably. The construction using one rotor for both elements is a very significant change over the old units in that only one casting is required.

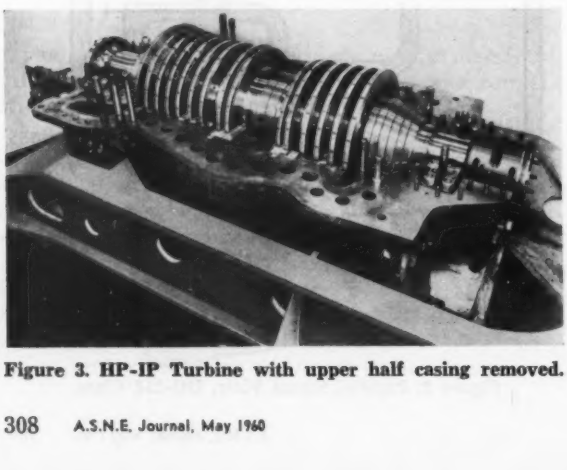


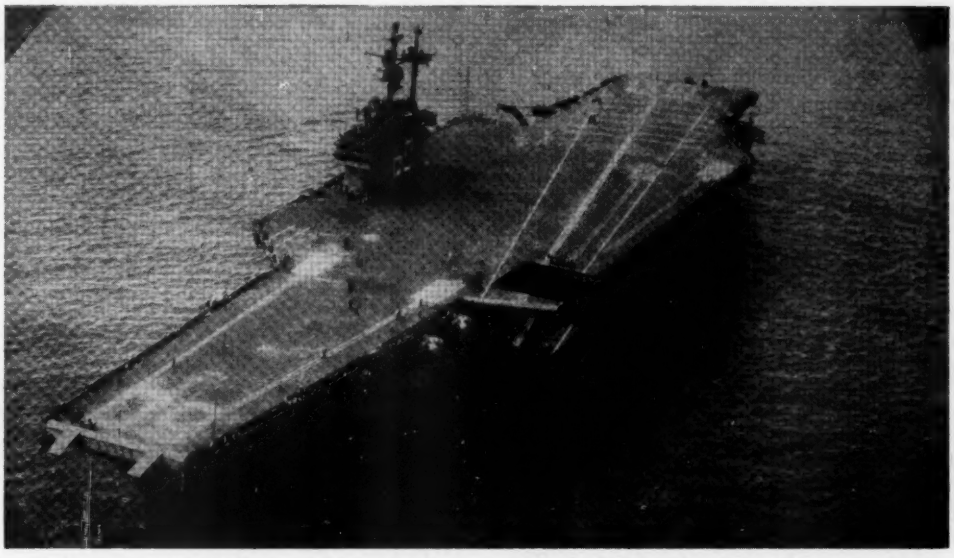
Figure 3. HP-IP Turbine with upper half casing removed.

FLOW ARRANGEMENT

The new units operate from the throttle handwheel. Transferring from series to parallel flow, and vice-versa, is done through linkages from the throttle. At lower powers, steam is directed from the steam chest through nozzle control vales to the HP element. After exhausting from the HP element, steam is passed through a transfer valve to the lower half of the IP turbine where the steam expands and does work through the IP element. At higher powers, steam is directed to both HP and IP elements. The transfer valve directs the HP exhaust steam to the LP turbine. During parallel operation, the IP element does more work than the HP. A schematic diagram is shown in Figure 4. The throttleman has no added valves to operate and can maneuver the ship and go through "transition" from series to parallel and back again without diverting his attention from his vital job.

CENTER PACKING

The center packing rings, that seal the difference in pressure between the HP and IP elements, have been considered a trouble area. In the event there is excessive vibration or a bowed rotor, the clearances of the center packing may open up which will result in a decrease in performance. Recently on one of the large aircraft carriers, a postlifting report indicated no change in the clearances of the center packing after 7000 hours of operation. This report is an indication that the center packing need not be a trouble area from a performance point of view.



The USS *Saratoga* (CVA-60) was the first of the new Aircraft Carriers to have Series-Parallel turbines.

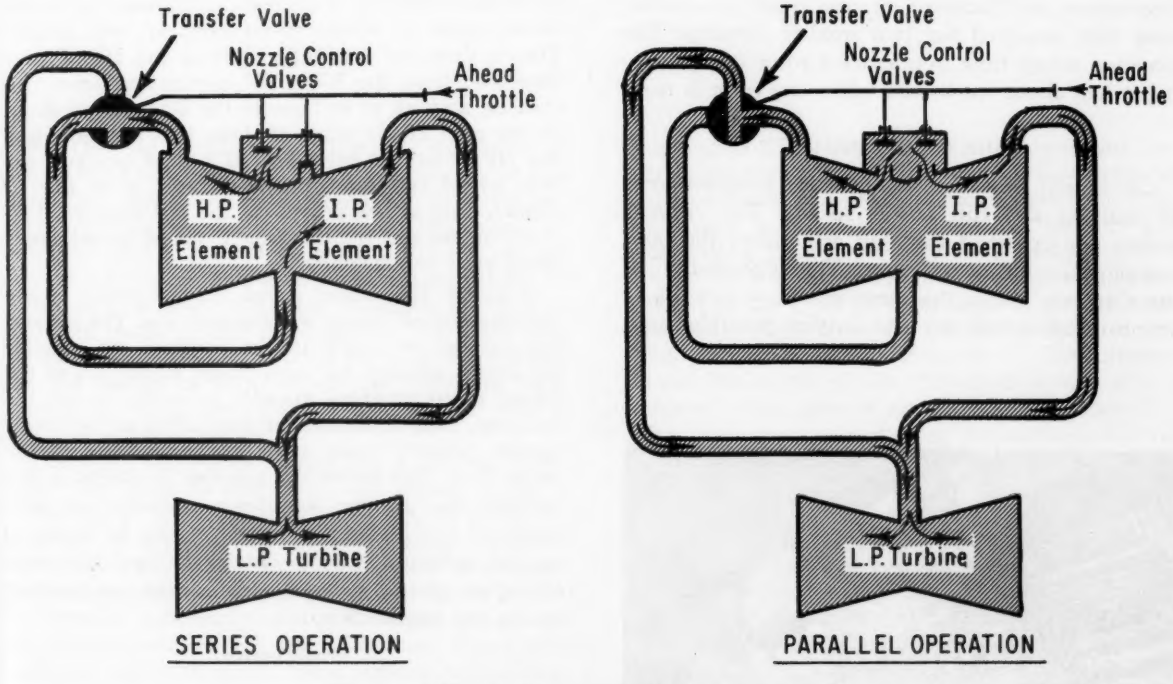


Figure 4. Schematic Diagram of Series-Parallel Operation.

MAINTENANCE

There is a maintenance advantage using series-parallel turbines in lieu of the cruising-HP combination used on earlier Destroyers. The advantage is in only one casing lift to inspect and repair the two elements. Casing lifts are expensive and time consuming.

Also, the series-parallel turbine has low pressure glands at both ends of the turbine which reduces gland leakage losses when compared with a

turbine which has the forward end gland exposed to first stage pressure.

The turbine inlet pressure of these newer ships is higher than World War II designs. This higher pressure complicates the horizontal joint bolting of a cruising turbine since a large flange and bolting would be difficult at the forward end of the smaller cruising turbine. This was a major factor in deciding to go to series-parallel turbines. A large percentage of turbine casings lifted on World War II destroyers were cruising turbines as a result of horizontal joint leaks at the high pressure end. The series-parallel turbine does not have this problem since the steam enters at the center of the turbine.

PRODUCTION ADVANTAGE

One of the long lead time items of a turbine is the rotor forging. The series-parallel turbine, along with the by-pass turbines, have a production advantage over the cruising-HP combination. This advantage is in having only one rotor forging. The cost of one rotor forging slightly longer and larger in diameter is less than the cost of two separate forgings. The time required for all the necessary inspections and handling of one rotor is a saving over that required for two smaller forgings. The machine set-up time to prepare a rotor for machining is just about cut in half when one rotor is used.

WHY SERIES-PARALLEL

Combatant ships are designed for good economy at cruising and full power speeds. The cruising radius and speed of the ship establishes the most economical point of operation. The "fightability" of the ship establishes the requirement to operate at or near full power for the longest possible time,

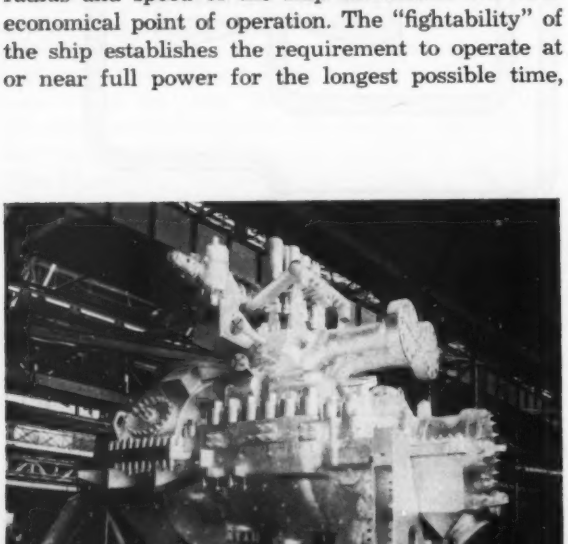


Figure 5. HP-IP Turbine for New Carrier.

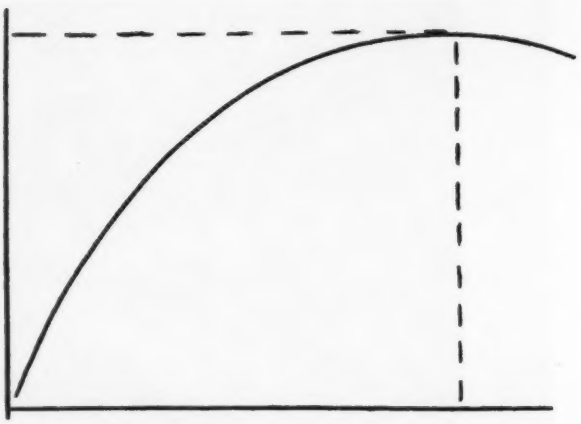


Figure 6. Wheel Speed/Steam Speed vs. Efficiency

which means good economy at full power. The above requirements make it necessary to design turbines with good steam rates at cruising and full power speeds. In order to obtain good steam rates for both conditions, it is necessary to have optimum wheel speed to steam speed ratio at both points. This is done by gradually shifting the HP-IP turbine load from the HP to IP element as power increases; so that, at full power the IP is doing about 70 per cent of the work of these two elements and the HP about 30 per cent. At higher powers, the best wheel speed-steam speed ratio is in the IP element and at low powers in the HP element. Figure 6 shows the relationship of wheel speed-steam speed ratio to efficiency.

If either the wheel speed or the steam speed changes, the efficiency will become less. The greater the number of stages in the turbine; the smaller the steam velocity for each stage, so the lower the wheel speed (turbine speed). In order to get the optimum ratio to obtain the best efficiency at lower speeds (power), more stages are needed; hence, the series flow. The fewer the number of stages in the turbine, the greater the steam velocity for each stage, so the higher the wheel speed. In order to get the optimum ratio to obtain the best efficiency at higher speeds (power), less stages are needed; hence, the parallel flow.

CONCLUSION

The series-parallel turbines are undergoing the best test that could be given; i.e., at sea on the ships. Figure 5 shows a completed unit. Very few trouble reports have been received by the Bureau on these units. Many hours of operation have been obtained on these units. The proof of their success will be in operation. So far, they appear to be good turbines for combatant ships.

NEW SHIP HYDRODYNAMICS LABORATORY

ACKNOWLEDGMENT

The following staff article is reprinted from the November, 1959 issue of "The Marine Engineer and Naval Architect."

On October 19, His Royal Highness, the Duke of Edinburgh, performed the opening ceremony at the new ship hydrodynamics laboratory at Feltham, England. This new laboratory of the Department of Scientific and Industrial Research will be a part of the Ship Division, National Physical Laboratory. It contains new and up-to-date facilities for hydrodynamic research and development, the main aim of the research being to build up basic knowledge for the design of ships which can maintain high speeds in rough seas without danger and with a minimum of discomfort.

The new laboratory comprises a towing tank, 1,300 feet long, 48 feet wide, and 25 feet deep, a water tunnel with a measuring section 44 inches in diameter, a sea-keeping and maneuvering basin 100 feet square together with the necessary workshops for making model hull and propellers. There is also a vibration laboratory and instrument laboratory for development, testing and calibration. These new facilities will supplement those already at Teddington and will make possible a much more rapid execution of tests than has been the case since the end of the war.

The Ship Division of the National Physical Laboratory was founded in 1908, with a gift from Sir Alfred Yarrow, for the construction of a towing tank at Teddington for experiments on models of ships. The Alfred Yarro tank, which was completed in 1911, is a concrete basin 500 feet long, 30 feet wide and 12.3 feet deep and is still in constant use. Increasing demands from industry for tank tests led to the provision of a second tank, completed in 1932. No. 2 tank at Teddington, is 680 feet long, 20 feet wide with a main depth of 9 feet, graduating to 2 feet for 180 feet at one end. The towing carriage has a speed of up to 30 feet per second. At the same time, with a gift from Sir James Lithgow, a propeller water tunnel was constructed. The Lithgow Tunnel has a test section 18 inches square with a designed water speed of about 30 feet per second.

By 1945, the demand from shipbuilders for resistance and propulsion tests increased to such an extent that, even with considerable overtime working, there was a nine-month delay in routine test work, leaving practically no time available for research. Accordingly, a case for a new tank was put to the Froude sub-committee who set up a panel, under the chairmanship of Dr. Ramsay Gebbie, to study the proposal. The main proposal was accepted in 1946 but, for a number of reason, chief among which was the difficulty of finding a suitable site, actual construction did not begin until 1955.

Although the use of scale models is the most economical method of investigating hull and propeller design, there are still great difficulties in predicting from model tests the actual resistance and power necessary for a ship. The various components of resistance and propeller forces do not follow any one natural law and this causes the problems generally

referred to as scale-effect. There are also many other problems associated with ship design which demand attention in addition to powering, such as cavitation, vibration, rough water behavior and maneuvering qualities. The new laboratory has been designed to assist the naval architect in these and other fields.

THE TOWING TANK

The large towing tank will enable much bigger models to be used than at Teddington. This is of particular importance for multi-screw ships as the model propellers will be of such a size that the scale-effect problems will be minimized. The larger hull models will also help toward a better understanding of the whole scale-effect problem.

The length of the tank which, at 1,300 feet, is nearly twice as long as the largest existing tank at Teddington is essential for a number of reasons. It will greatly expedite normal test procedure since a number of ships' speeds can be simulated in one run down the tank, thus reducing very greatly the time lost between single speed runs on a short tank while waiting for the water surface to become calm. In experiments in waves it is often desirable to simulate actual sea states with irregular waves. A model advancing into such waves experiences unsteady forces resulting in non-uniform pitching and heaving. To compare the relative performance of alternative models, it is necessary to ensure that each model will experience sufficient cycles of motion to enable reliable statistical information to be obtained.

In propeller design, the increase in power to be developed with the increase in sizes and speeds of ships makes the avoidance of cavitation increasingly difficult. Thus, there is a growing need for more knowledge on the behavior at high speeds of hydrofoil sections suitable for use in marine propellers, both to learn how to avoid or delay cavitation or, in the end, to live with it. These tests require a high-speed carriage and long tank since the accelerating and braking distances of such speeds are great. It is also necessary to have enough time at steady speed to record the essential measurements. Such data are of value, not only in propeller design, but also for such things as hydrofoil craft, shaft appendages and stabilizing fins.

The towing carriage is designed to tow ships models up to 5 tons in weight and 40 feet in length. The maximum speed attainable is 50 fps or 30 knots. This speed is not required for towing displacement hulls but for work on high speed craft, hydrofoils and propellers. The carriage has four girders forming a square framework, 50 feet by 50 feet externally, and completely open inside giving a space 36 feet square. This space can accommodate a fore and aft girder containing dynamometers and other instruments. This girder is portable to give flexibility in carrying out different types of tests.

To decrease the effects of track deflection, and thus assist in providing undisturbed and uniform motion, the carriage is driven by four twin-wheeled self-steering bogies, on which the frame is, in effect, pivot-mounted by a system of rubber compression springs. Each bogie is powered by a 300 hp peak rating d-c motor. The total peak power of 1,200 hp has been calculated to provide, with adequate margin, sufficient power to accelerate the carriage, which will weigh nearly 40 tons fully equipped, at the maximum rate without wheel slip.

The normal method of braking will be regenerative but, at high speeds, a system of mechanical fric-

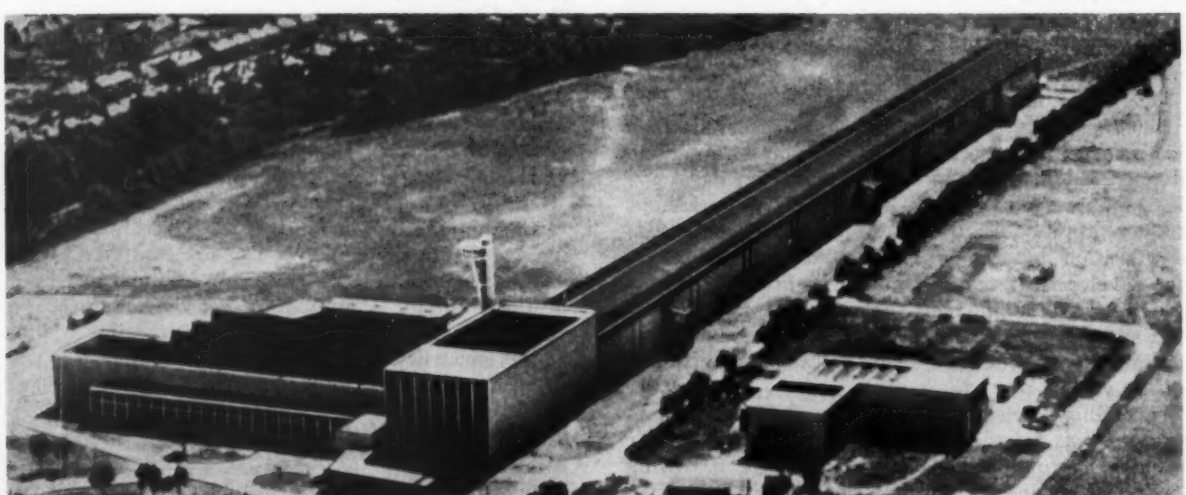


Figure 1. This view of the Feltham tank is familiar to regular users of London Airport.

General arrangement plan of the new facilities

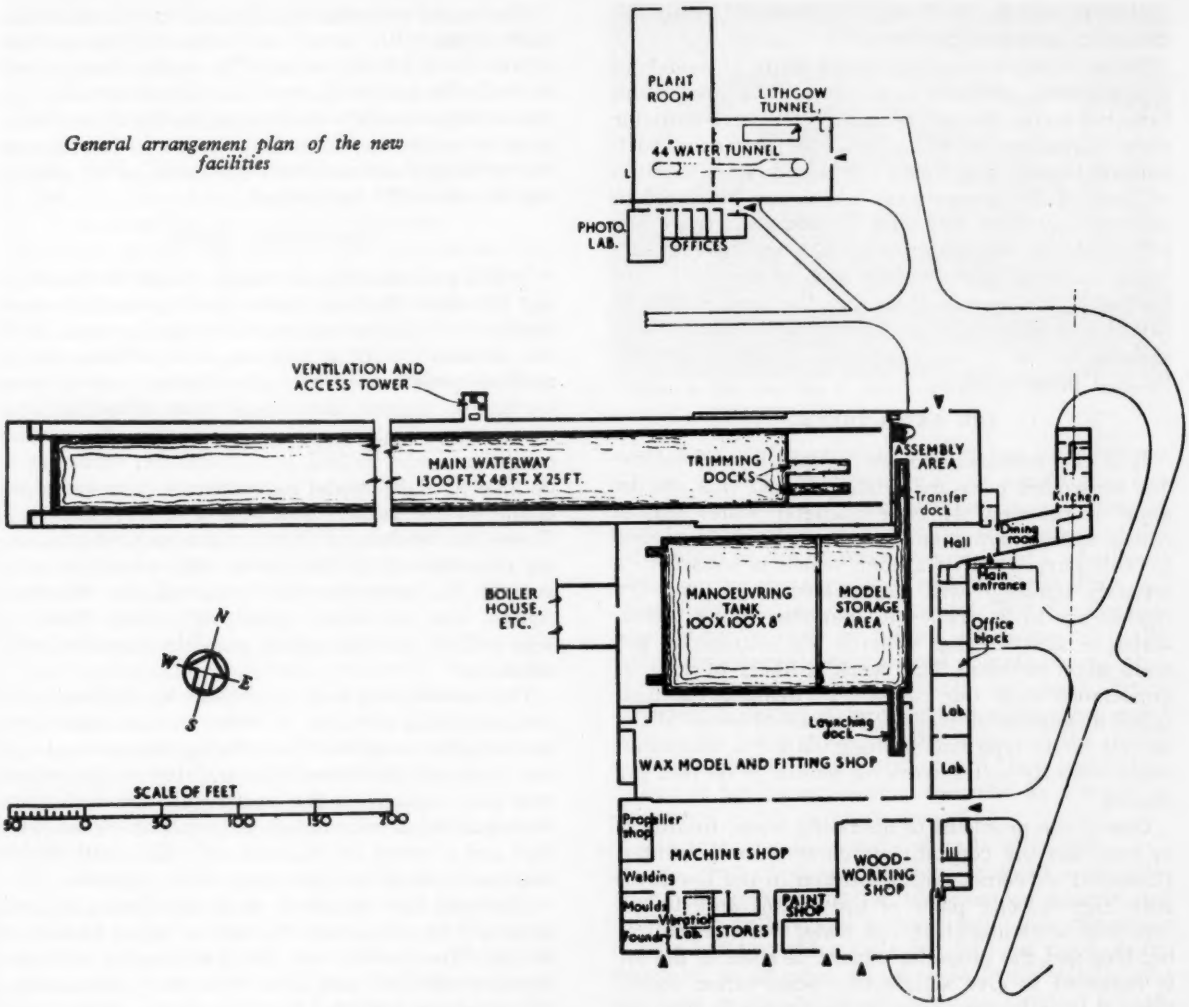


Figure 2. General arrangement plan of the new facilities.

tion brakes will be brought into use which are spring-operated and held off pneumatically so that they fail to safety in the event of loss of air supply. To limit the duration of the test run, track switches have been installed to bring on both electrical and mechanical brakes and bring the carriage to rest with the maximum deceleration of 0.25 g. Should all these systems fail, an aircraft-type hydraulic arrester gear has been fitted. A shock-absorbing nylon harness on the underside of the carriage will engage hooks supported on the inside face of the tank wall. These hooks are connected by steel cables to the arrester ram.

The investigation of the behavior of vessels in a seaway demands the generation of regular and irregular wave systems in the tank. At one end of the tank a wave-maker has been installed capable of making waves from 5 feet in length and 6 inches in height to 40 feet in length and 2 feet in height from crest to trough, with a number of other combinations within these limits. The wave-maker takes the form of a wedge-shaped plunger, 17 feet in height, which spans the tank and tapers almost to a point at the bottom. The front face is curved to follow a theoretically ideal contour and is true to within $\pm 1/8$ inch over the whole frontal area. The plunger moves vertically on slides on the end wall of the tank and is driven by hydraulic rams from a pump which operates normally on a sinusoidal pressure cycle to give a regular train of waves. By varying the pressure cycle it is possible to generate irregular wave systems more typical of average ocean sea states. To prevent deflection of the waves from the other end of the tank an end beach has been provided. This is a steel structure having a curved sloping surface, continuous below water and slotted in

and above the water. It can be raised or lowered by means of buoyant chambers.

When tests are being made with a model in smooth water, she creates her own wave system and time has to be allowed between successive runs for these waves to die down. In order to reduce such waiting time to a minimum a second beach is fitted in front of the wave-maker which can be raised to the surface when required. In addition, there are side beaches, consisting of continuous curved surfaces, running along either side of the tank and hinged to the tank wall so that they can either be raised to a vertical position clear of the water when making waves, or let down and partly submerged for still water testing.

THE WATER TUNNEL

It is also necessary to test hydrofoil sections under controlled pressure conditions and this can be done in the new 44 inch diameter water tunnel where special dynamometers have been developed for this purpose. This tunnel, which is housed in a separate building, will also enable large propeller models up to 24 inches in diameter to be tested, which is another step towards the solution of the scale effect problem. This work is likely to grow in importance with the increase in demand for high speed in ships of all classes. The tunnel is one of the largest of its type and is designed for a maximum water velocity in the working section of 50 feet per second.

One of the problems of operating water tunnels is to maintain the constant air content in the water. Dissolved air comes out of solution in the low-pressure high-velocity parts of the circuit and, unless removed or re-absorbed, the water becomes full of bubbles and the propeller cannot be seen. If the air is removed to give satisfactory observation conditions, it is no longer typical of sea water. In the new tunnel it was decided to re-absorb the air during each circuit by taking the water deep down below the measuring section and subjecting it to high pressure while moving slowly.

To this end, the lower horizontal limb of the tunnel is 10 feet in diameter and 180 feet below the measuring section. The vertical limbs are 87 feet apart, center to center, the holes being lined first with reinforced concrete rings and then steel tube.

The test section is 7 feet 4 inches long followed by a long diffuser leading to a 45-degree mitered corner to the impeller. The latter is mounted vertically in the down limb of the tunnel giving a hydrostatic head of 35 feet at the top to avoid cavitation at the impeller. The axial-flow impeller has a diameter of 92 inches and has a variable-speed drive of 1,052 hp maximum continuous rating. Blade pitch can be adjusted at standstill to obtain high pumping efficiency over a wide range of conditions and impeller speed is closely controlled to the preset value by a speed servo.

The model propeller is mounted on a downstream shaft fitted with thrust and torque dynamometers driven by a 300 hp motor. The measurements will be made by hydraulic capsules. The pressure in the test section can be varied from near zero to six atmospheres absolute. Provision is made for filtering and cooling the tunnel water as well as for adjusting the dissolved air content.

SEA-KEEPING BASIN

In the past, the tests in rough waters in the existing National Physical Laboratory tanks have been confined to head-on and stern-on regular seas. With the demand for higher ship speeds and the advent of nuclear power, with its higher initial cost, it is essential to ensure that these new ships be able to maintain high speeds at sea under all weather conditions, good or bad. It is, therefore, necessary to be able to make model experiments in waves at all angles to the model's course and in irregular seas. These can be done in the new sea-keeping tank using remotely controlled models and considerable ingenuity has gone into the design of the necessary control and recording equipment, which must be kept as light and compact as possible consistent with reliability.

The sea-keeping tank is 100 feet by 100 feet with a water depth of 8 feet. A continuous plunger-type wave-maker, capable of producing waves up to 15 feet long and 9 inches high, is fitted on the south wall and a beach on the north wall. Later it is intended to fit an articulated wave-maker on the west wall and a beach on the east wall. This will enable confused seas to be generated when desired.

The tank has two small docks for fitting up and trimming of models which may be up to 10 feet in length. The models will be free-running and remotely-controlled and data from their instruments will either be recorded in the model or telemetered ashore.

The Ship Division is collecting information on the sea-states characteristic to certain areas of the

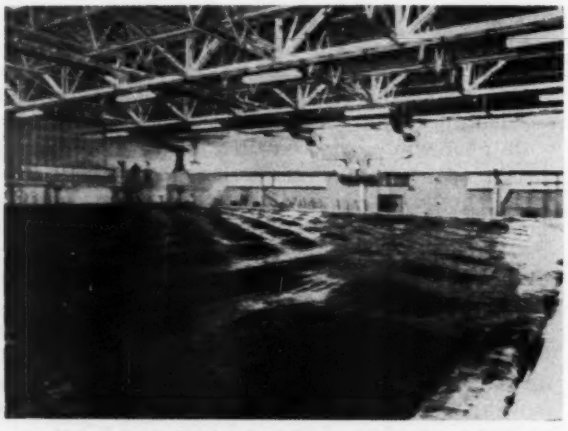


Figure 3. The 100 foot square sea-keeping basin.

world and it is intended to correlate these characteristics with Beaufort numbers. Although conditions at sea consist of very complex wave systems, it is possible to break down these complex situations into simple components. These simple components can be reproduced in the sea-keeping tank and the behavior of the model under the influence of each component can be studied. The total effect of a given situation can then be calculated.

Adjacent to the sea-keeping tank is a maneuvering tank, 60 feet by 100 feet. This area includes a channel leading from the launching dock in the model fitting shop to the transfer dock, from which models will be lifted to the trimming docks of the main towing tank by an overhead crane standing in the assembly area.

ANCILLARY LABORATORIES

A laboratory has been set aside for the study of vibration including entrained water effects. The permanent equipment of this laboratory includes a water tank, 20 feet by 40 feet by 16 feet, and an overhead suspension grillage designed to have a very high natural frequency.

Two laboratories are also provided for the study of instrumentation, one being allocated to design and development of mechanical and electronic instruments, and the other to general calibration and maintenance of instruments. The dynamometers for rough and smooth water measurements and the instruments for recording carriage speed, torque, thrust and other quantities, have been designed and developed in Ship Division.

Three large workshops are provided for metal-working, wood-working and model manufacture. All model hulls, which are made in paraffin wax, wood or, in special cases glass fiber laminate, are made on the premises and special facilities include wax melting plant and hull profiling machines for wax or wood models and a small shop ventilated to suit work in resins and the spraying of cellulose and other finishes.

The metal and wood-working shops are equipped with standard precision machines for instrument manufacture, pattern-making, etc., and with special machines for propeller manufacture. A small foundry and welding shop are also provided.

CONSTRUCTIONAL DETAILS

The subsoil of the Feltham site made it necessary to keep the main bulk of the towing tank above ground level which means that the water level in the tank is considerably higher than that in the other facilities. This has necessitated the provision of an overhead crane to transfer models from the transfer dock into the trimming dock of the main tank.

The dominant engineering problem in constructing the ship towing tank was the creation of a highly accurate and stable track for the towing carriage. This is of paramount importance since irregularities of the track, however small, would give rise to accelerations and decelerations which, even if partially corrected by automatic speed-holding devices fitted to the carriage, would have a significant effect on the dynamometer record of the drag and other forces acting on the model. The dynamometers generally used in towing tanks are virtually undampened and ideally should operate from a platform moving at absolutely uniform speed. Track accuracy is particularly important when slow speed models are being tested as the forces on the model may be quite small and could be completely swamped by the oscillations recorded as a result of variations in the carriage velocity.

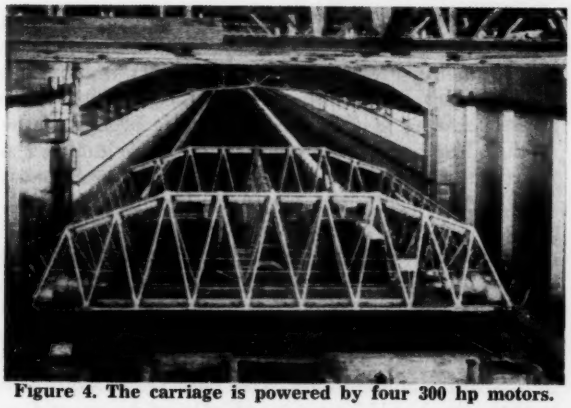


Figure 4. The carriage is powered by four 300 hp motors.

The track itself consists of rails of carbon manganese steel of special section designed with suitable head dimensions for the carriage wheels and side guide rollers and to have minimum distortion during welding. The rails are laid on rigid chairs designed to transfer all carriage loads solidly into the tank walls and to provide fine vertical adjustment by shimming between the machine surface of the chair and the machine bottom of the rail and horizontal adjustment by means of fine thread brass bolts. The correct vertical height of the chairs was achieved by the use of water-level gauges with micrometer heads. The use of a water-level ensures that the chairs are set up parallel with the earth's surface rather than in a straight line in space which would be the case with optical sighting. The maximum difference over a 1,300 foot length of the tank is nearly ½ inch. The track has been levelled and aligned so that the vital track surfaces truly follow a line parallel with the earth's surface and straight within a tolerance of ± 0.005 inch over the complete length of the tank.

TOWING CARRIAGE

The carriage dynamometer boom is normally located on the centerline of the carriage but two alternative positions on either side of the center can

be used. The dynamometer boom has a platform on either side, one of which is fixed and the other capable of being lowered by push-button control into any position down almost to water level so as to give operating staff the best possible access to the model. Power for the carriage is provided by a Ward-Leonard set via a system of rigid conductor rails laid along the outside of the tank walls in conjunction with collector arms reaching down from the carriage. This system, which has not been used in this form in any existing tank, is economical in space requirements and has been specially developed for this project. Both sides of the tank are used and there are 12 conductors in all made up of T-section copper bars. The carriage is equipped with a speed-holding servo which maintains any set test speed between 10 and 50 feet per second within 0.1 per cent. This apparatus also includes provision for limiting the acceleration rate to a pre-set value. The mechanical friction brakes of the carriage operate on a separate brake rail which is erected on both sides of the tank and which consists of a 7 inch by ⅜ inch thick mild steel strip laid on end. The carriage shoes envelop the upper part of the strip and, in operation, clamp on both sides in the manner of a car disc brake.

The length of tank limits the duration of the test run at the maximum speed to about 5 to 7 seconds and clearly it is necessary to utilize the length fully to achieve this. Track switches are installed so that, at high speed, the carriage can be brought to rest automatically. These switches, which are duplicated for safety, bring on both the electrical and mechanical brakes and bring the carriage to rest with a maximum deceleration rate of 0.25 g. A further set of track switches is fitted further down towards the west end of the tank to enable a maximum length of tank to be employed for low-speed runs, that is at speeds up to 20 feet per second. Selection of speed, on the carriage control desk, automatically brings into use the appropriate track switches.

The wave-maker plunger is of steel fabrication weighing some 20 tons. All internal and external steel surfaces have been specially treated to resist corrosion, the final outside coating being neoprene brushed on by hand. The guide system on which the plunger moves consists of four vertical lengths of heavy-section rail with the head specially machined so that each rail carries four lengths of stainless steel running strip ground to a fine finish. These rails are bolted to heavy steel plates attached to the wall forming the west end of the tank. Guide boxes are bolted to reinforcing pads on the back of the plunger and these contain a system of stripper pads having antifriction rubbing faces backed by special rubber springs which embrace the head of the guide rails and make contact on the running surfaces.

The motion of the plunger is automatically controlled by a specially-developed electro-hydraulic servo mechanism. This, in effect, continuously monitors the actual physical position of the plunger relative to the correct position according to the control setting and applies correcting action if any error exists.

TUNNEL CONSTRUCTION

The construction of the water tunnel was a considerable enterprise. The shafts and gallery were first excavated and lined with pre-formed concrete sections. The cylindrical pressure shell and its component sections were then brought to the site, lowered and welded *in situ*. Welding has only been possible from the inside and this has involved a degree of accuracy in mating the sections and weld preparations rarely met with in sections of this size, and all welds have been ultrasonically tested. The tunnel has a by-pass circuit through which the water can be conditioned to suit the requirements of any particular experimental set-up. It is normally cooled and filtered and refrigeration plant, heat exchangers and fine particle filters are included in the tunnel auxiliary plant. In addition, the water can be deaerated if required and the pressure conditions in the working sections set and automatically maintained at any level between 6 atmospheres absolute and near vacuum. The pressure control system has been specially developed, based on past tunnel experience, and represents a new approach to this problem.

The propeller motor has a dynamometer-mounted rotor with oil-lift bearings which are almost frictionless and this, together with the special efforts made in balancing the motor, and the dimensional accuracy of significant components, will help to eliminate errors in torque measurement. Similar attention has been paid to the thrust bearing gear and this, together with the refined apparatus to be used by the laboratory for thrust and torque measurements, is expected to yield highly accurate test data.

Both the pump rotor and the dynamometer motor are supplied by a Ward-Leonard set and are equipped with automatic speed-holding equipment designed to hold any set speed with an accuracy of 0.1 per cent.

All the rotating machinery and other plant associated with the water tunnel is located in a separate plant room, ground insulated from the tunnel laboratory. The laboratory contains the working section as mentioned above, the main control desk and all the additional instrumentation and portable apparatus normal for such work.

In the wax model shop, facilities are provided to carry out the casting, profile-cutting, finishing and fitting-out of model hulls up to 35 feet long by 7 feet 6 inch beam. The installation includes wax melting vats and pump distribution system supplying molten wax through closed vanes to the molding boxes. These boxes permit the simultaneous molding of several large models. A large specially-designed machine for accurately machining the profiles of

models has been installed. This is believed to represent a considerable advance in accuracy and versatility compared with machines at present installed in similar establishments throughout the world.

The buildings for the Feltham Laboratory were designed by the chief architect's division of The Ministry of Works, while the engineering plant and services were designed by the chief engineer's division.

DISTRIBUTION OF WORK

With the new laboratory in full commission the Ship Division of the National Physical Laboratory will have the following facilities:

No. 1 tank will be the 500 foot Alfred Yarrow tank at Teddington;

No. 2 tank, the 680 foot towing tank at Teddington;

No. 3 tank, the 1,300 foot towing tank at Feltham;

No. 4 tank, the maneuvering and sea-keeping basin at Feltham.

No. 1 water tunnel, the 18 inch by 18 inch Lithgow tunnel at Teddington;

No. 2 water tunnel, the 44 inch diameter tunnel at Feltham.

In general, tests of commercial ship models in smooth waters will be carried out as at present in No. 1 tank, and tests of propellers in open water for the same models in No. 2 tank. Tests of commercial models in rough water will be carried out in Nos. 3 and 4 tanks. Commercial tests of propellers in a cavitating condition will, in general, be carried out in No. 1 tunnel.

It is expected that a great deal of the research work will be carried out in Nos. 3 and 4 tanks as it is believed that increasing emphasis will fall on sea-going qualities of ships and the new facilities at Feltham will be extremely valuable in this field. Various other researches, such as that on skin-friction and roughness, ships' model correlation, wave-making resistance and boundary layer investigations will also be carried out in the new tank where larger models can be used than is possible in the existing Nos. 1 and 2 tanks.

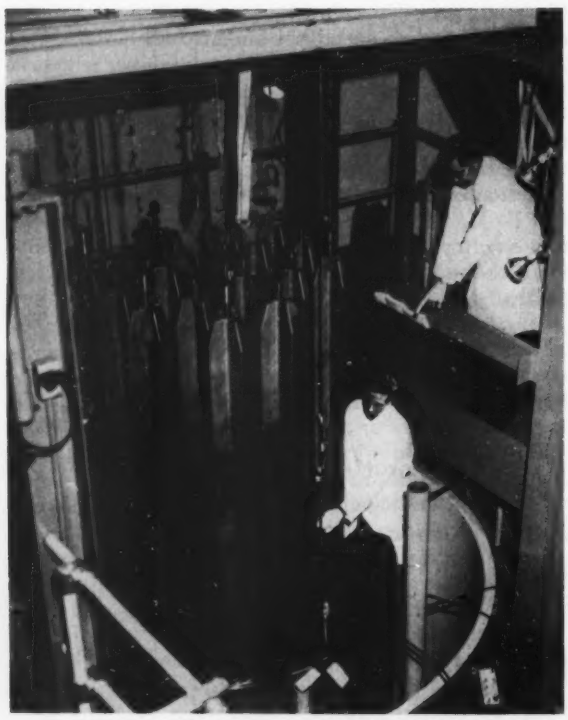
No. 2 tunnel, with its large diameter of 44 inches, will be used mostly for research on cavitation of marine propellers and hydrofoils. This work is likely to grow in importance with the increasing demand for high speeds in ships of all classes. Research aimed to reduce vibration in ships, which is mostly concerned with that excited by the propellers, will also be carried out at Feltham in the vibration laboratory.

The staff at the Feltham Laboratory is under the direction of the superintendent of the Ship Division, Dr. F. H. Todd, B.Sc., M.I.N.A., who returned to this country two years ago after a five-year appointment at the David Taylor Model Basin in the United States.

A research program in a new field of electric power production has been undertaken in a jointly supported effort by ten large electric power companies. The utility group, represented by American Electric Power Service Corporation as agent, will cooperate with the AVCO Corporation in the research and development of a power system based on principles of magneto-hydrodynamics. The essential idea involves generating an electric current by passing a superheated, ionized gas through a magnetic field, instead of a heavy armature. A small experimental device at the AVCO-Everett Research Laboratory has attained more than a 10 KW output. Preliminary information indicates that such a generator can be 25 per cent more efficient than conventional power generation systems. The General Electric Company is also reported to be conducting research in the field, and studies by the Republic Aviation Corporattion indicates that these principles may be applied to a practical means of converting thermo-nuclear power directly into electricity.

—from SCIENCE NEWS LETTER
December 5, 1959

Nuclear Core for N. S. Savannah Goes Critical in Dry-Land Test



Babcock & Wilcox Photograph

Assembling Nuclear Reactor Core for N. S. *Savannah*

The nuclear power core which will drive the N. S. ***Savannah,*** the world's first atom-powered merchant ship, has achieved a sustained chain reaction at The Babcock & Wilcox Company's Atomic Energy division laboratory. It is believed to be the first propulsion reactor power core known to achieve criticality before installation.

The test confirmed nuclear design and engineering calculations, and provided first hand experience for the safe installation of the core aboard the ***Savannah.***

Weighing more than 15 tons, the core is made up of 32 fuel elements containing 4.2 and 4.6 per cent enriched uranium, 21 control rods, and internal "hardware." It contains the heaviest known quantity of uranium ever used in a commercial critical experiment laboratory test.

The core was tested in a tank 9 feet in diameter and 17 feet high, filled with more than 10,000 gallons of deionized, or purified, water. Each fuel element weighs about 800 pounds and contains 164 stainless steel rods loaded with uranium pellets. Each of the 21 control rods, which are used to regulate the reactivity and to compensate for fuel consumption within the reactors, weighs 225 pounds. The core contains sufficient fuel to propel the ***Savannah*** more than 350,000 miles without refueling.

The ***Savannah*** is being built under President Eisenhower's "Atoms for Peace" program by the U. S. Atomic Energy Commission and Maritime Administration. In addition to designing and building the ship's nuclear propulsion system, Babcock & Wilcox is also training the crew for the ship, which will be operated for the Government by States Marine Lines.

The vessel was launched last July 21 by its builders, New York Shipbuilding Corporation, after it was christened by Mrs. Mamie Eisenhower.

IRVING GRANET

SOME SELECTED PROPERTIES OF CESIUM

THE AUTHOR

attended the Cooper Union and received the degree of Bachelor of Mechanical Engineering in 1944. Employed in 1944-45 on Navy Torpedo project as project engineer on stress and vibration studies, he subsequently served two years with Air Corps overseas as Flight Engineer. In June 1948 he received the degree of Master of Mechanical Engineering from the Brooklyn Polytechnic Institute and in 1949 received Professional Engineering License in New York. Since 1947, he was employed by Foster Wheeler Corporation as Project Engineer, Research Department, then as Director of Staff Engineering, Nuclear Energy Department, and later as a consultant to this department. In 1955-56 he attended the Oak Ridge School of Reactor Technology at Oak Ridge, Tennessee. He has taught Heat Transfer and Thermodynamics at Brooklyn Polytechnic and is presently completing the requirements for the degree of Doctor of Mechanical Engineering. He has published over thirty articles on gas properties, heat transfer thermodynamics and applied mechanics. He is presently with the Plasma Propulsion Project at Republic Aviation Corporation and is an Adjunct Asst. Professor of Physics and Engineering at Long Island Univrsity.

CESIUM IS AN ELEMENT which has recently been seriously considered as the propellant in space propulsion systems. Cesium is easily ionized, has a low ionization potential and a low boiling point. It is, therefore, pertinent to briefly analyze some of these properties, and discuss methods of estimating for those properties that are not readily available in the literature.

Cesium (Caesium) is an alkali metal, silvery white in appearance, and soft and ductile. It is the most electropositive of the metals and chemically behaves similar to potassium. Upon exposure to moist air it takes fire spontaneously and violently, liberating hydrogen. The metallic form is usually handled by immersion in an inert gas or kerosene. Because it is toxic in relatively small quantities, care must be exercised to prevent it from being ingested (in any form), and it should further be prevented from contacting the body as ulcerous lesions can occur from such contact. The principal uses of cesium have been photoelectric cells, scintillation counters, a "getter" in low voltage vacuum tubes and in infra-red detecting instruments (snooperscope). Production of the material is limited and to 1956 less than 300 tons had been produced.

PROPERTIES

Unfortunately, some of the basic data that are required to establish a set of thermodynamic properties for this material are not consistently given in the literature. For example, the boiling point at one atmosphere is reported in several sources as being 670°C, 685°C, 690°C and 705°C. The heat of vaporization, vapor pressure data, etc., are similarly in doubt. It is, therefore, apparent that the data from one set of tables cannot be used interchangeably with other sets without causing serious errors. The writer has therefore chosen values which appear to be reasonable and consistent and these are listed in Table I.

TABLE I

Atomic weight	132.91
Atomic number	55
Melting point	28.5°C—83°F
Boiling point (1 atmos)	705°C—1301°F
Vapor pressure	See Figure 1
Density	1.84 gm/cc @ 28°C
Heat of fusion	500 cal/mol
Heat of vaporization	16,000 cal/mol
Specific heat of the solid	7.52 cal per °C per mol
Specific heat of the liquid	7.60 cal per °C per mol
Density (solid) @ 20°C	1.90 gms/cc

Vapor pressure data for the vapor in contact with the liquid are given in Figure 1. Since the monatomic species are also present in both phases these values represent a "normal" vapor pressure rather than that for a single species.

The low pressure specific heats for both the monatomic and diatomic gases are given in Figures 2 and 3 respectively. It is to be noted that these values are for the given species if *only* that one is present. In order to calculate the properties of an equilibrium mixture of these gases, it is necessary to know their equilibrium concentrations. For the reaction,

$$Cs_2 \rightleftarrows Cs + Cs \quad \ldots\ldots (1)$$

the equilibrium constant K is given as:

$$K = \frac{[Cs]^2}{[Cs^2]}$$

where [ ] denotes concentrations. Thus if a volume of Cs_2 containing initially M molecules is heated, some of them will dissociate and these will be denoted as N; then the concentrations of Cs_2 and Cs at equilibrium are (M−N) and 2N respectively. The equilibrium constant is therefore

$$K = \frac{4N^2}{(M-N)} \quad \ldots\ldots (2)$$

If N is small compared to M,

$$K = \frac{4N^2}{M} \text{ and } N = \tfrac{1}{2}\sqrt{KM} \quad \ldots\ldots (2A)$$

The foregoing is in principle quite straight forward and enables one to calculate the amount of each gas species present and consequently the

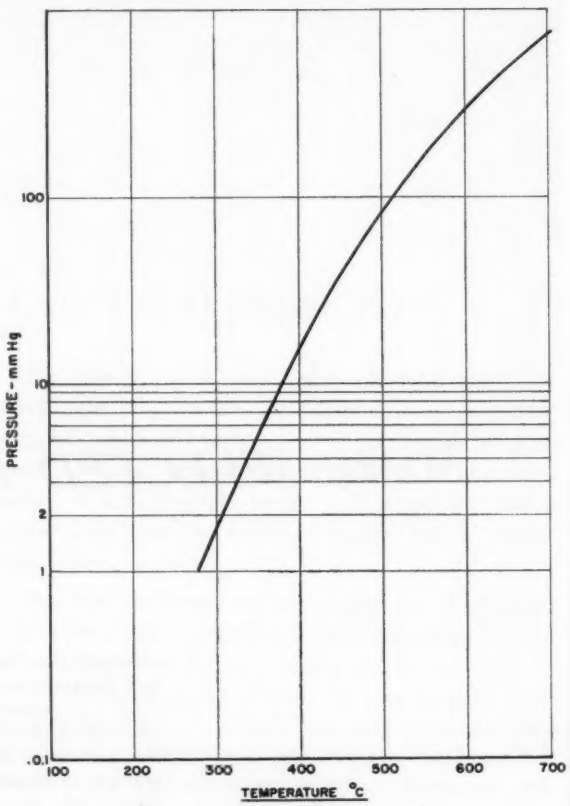


FIG. 1 VAPOR PRESSURE OF CESIUM

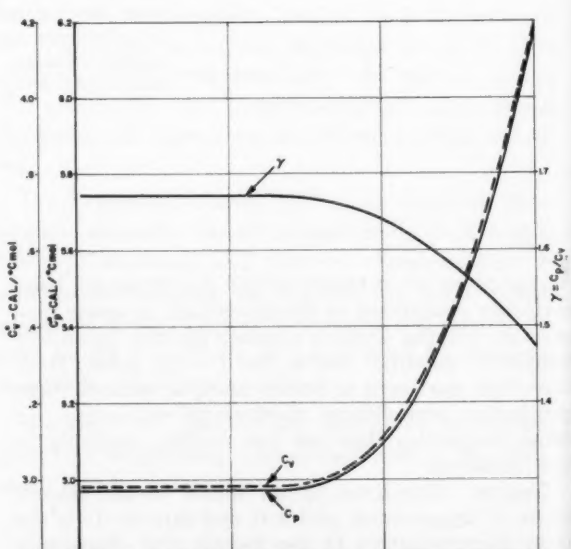


FIG. 2 LOW PRESSURE SPECIFIC HEAT OF MONATOMIC CESIUM VAPOR

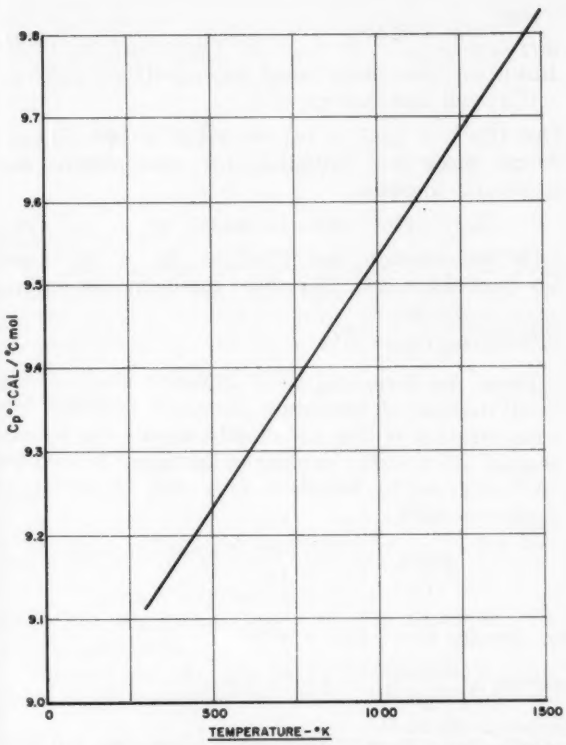


FIG. 3 LOW PRESSURE SPECIFIC HEAT OF DIATOMIC CESIUM VAPOR

density, specific heat, enthalpy, etc. However, there is a serious question as to the interpretation of the data in the literature. The available values appear in references (2) and (3) and disagree violently at low temperatures. At temperatures above the normal boiling point there is agreement but it is not evident that the value tabulated is for the desired state change, i.e., gas to gas. This point needs to be resolved if the properties of the equilibrium mixture are to be calculated. From the data given it appears that the monatomic gas predominates for most temperatures.

As the temperature of monatomic cesium is increased some of the atoms become ionized and a process such as given below in equation (3) takes place. The energy required for the complete ionization of cesium is 3.7×10^{-12} ergs per mol. By applying the theory of chemical equilibria to this process an equation for the degree of ionization of the gas can be

$$Cs \rightleftarrows Cs^+ + e \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

derived and is given by Fermi.[5] This equation was first derived by M. N. Saha and is named for him. Using the following notation, Saha's equation for the reaction of Equation (3) can be written as:

$$n\left(\frac{x^2}{1-x}\right) = \left(T^{3/2}10^{-19{,}555/T}\right)3.9\times10^{-9} \quad \ldots\ldots (4)$$

where

T = absolute temperature $-°K$

$n = [Cs]+[Cs^+]$ = total concentration of cesium

x = degree of ionization $= \dfrac{[Cs^+]}{[Cs]+[Cs^+]}$

$[\ ]$ = concentration

and

$nx = [Cs^+]$

$n(1-x) = [Cs]$

From Equation (4) one can arrive at a more familiar form by taking $\log_{10}$ of both sides:

$$\log_{10} n\frac{x^2}{1-x} = -\frac{19{,}555}{T} - 8.41 + \frac{3}{2}\log_{10} T \quad \ldots\ldots (5)$$

(Note that $\dfrac{n^2x^2}{n(1-x)}$ is the equilibrium constant for the process of Equation (3).)

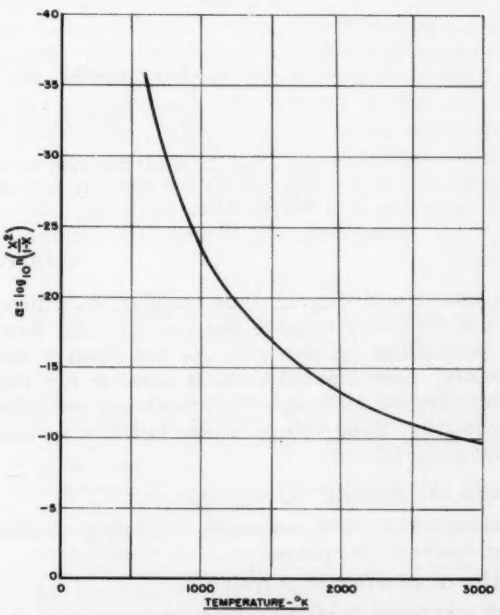


FIG. 4 IONIZATION FUNCTION FOR MONATOMIC CESIUM VAPOR-(BASIS-SAHA EQUATION)

Figure (4) is a plot of Equation (5) as a function of temperature. For the range plotted all of the values are negative. Denoting the right hand side of Equation (5) by α and taking anti-logs,

$$n\left(\frac{x^2}{1-x}\right) = 10^{\alpha} \quad \ldots\ldots (6)$$

Assuming that the vapor acts as a perfect gas, the temperature, pressure and concentration are related by the familiar equation,

$$p' = n'KT \quad \ldots\ldots (7)$$

centration), K = Boltzmann's constant and T is the absolute temperature. For a mixture such as this, the total pressure is therefore,

$$p=(n'_{Cs}+n'_{Cs^+}+n'_e)KT \quad \ldots\ldots(8)$$

and $n'_{Cs^+}=n'_e$

If the diatomic species is also present it is necessary to include a term n'_{Cs_2} in Equation (8) and to include Equation (2) in the analysis. Therefore, in principle, the concentrations of all of the constituents are known from the foregoing.

As a simple example, and to obtain an estimate of the degree of ionization, assume that we have a gas volume of monatomic cesium at 1500°K and say 100 mm Hg. Taking the standard number density at zero °C and 760 mm as equal to $2.6871\times10^{19}/cm^3$, one obtains a number density at 1500°K and 100 mm Hg as $.06434\times10^{19}$ particles/cm³. This equals the number of ions plus an equal number of electrons plus the un-ionized atoms. From Figure 4, $\alpha = -16.7$ and there $n\frac{x^2}{1-x} = 10^{-16.7}$ or

$$\frac{n^2x^2}{m(1-x)} = 10^{-16.7} \quad \ldots\ldots(9)$$

But it was previously noted that $nx=[Cs^+]$, $n(2-x)=[Cs]$ and also that $nx=[e]$.

But $[Cs^+] + [Cs] + [e] = .06434 \times 10^{19}$. Substituting these into Equation (9), one obtains the quadratic equation,

$$[Cs^+]^2\times10^{16.7}+2[Cs^+]=.06434\times10^{19} \quad \ldots\ldots(9A)$$

with the solution that $[Cs^+] = .25 \times 10^{1.15}$ and $Cs \cong .06434 \times 10^{19}$. Therefore the degree of ionization is $\frac{.25+10^{1.15}}{.06434\times10^{19}}\cong0$

From the foregoing it is apparent that for the small degrees of ionization discussed thus far. the concentration of the ion closely equals the square root of the number density of particles divided by $10^{-\alpha}$ as given in Equation (10) and is similar to Equation (2A).

$$[Cs^+]\cong\sqrt{\frac{[Cs]+[Cs^+]+[e]}{10^{-\alpha}}} \quad \ldots\ldots(10)$$

For 3000°K, the number density is $\sim .032 \times10^{19}$,

$\alpha = -9.71$ and $[Cs^+]$ becomes $\sqrt{\frac{.032\times10^{19}}{10^{9.71}}} = .179 \times 10^{4.64}$

$\frac{.179 \times 10^{4.64}}{.032 \times 10^{19}}$ and the degree of ionization is equal to $= 5.6 \times10^{-14.4}$, which is still quite small.

TRANSPORT PROPERTIES

For analysis of a cycle, heat transfer, fluid flow, etc., it is necessary to have the viscosity and thermal conductivity of the gas. As has been noted previously, experimental data is lacking for this element. Several methods of approach are available for *estimating* these values. These fall into several categories as follows:

1. Use of "classical" kinetic theory.
2. Comparison with elements exhibiting similar properties, i.e., potassium.
3. Use of generalized correlations.[10]
4. A combination of the above.

At present the paucity of fundamental data precludes even such estimates. The method given below is suggested as a first rough approximation.

Jeans [11] notes that the ratio of $K/c_v\mu$ can be approximated by ¼ $(9\gamma - 5)$ where

K = thermal conductivity
c_v = specific heat at constant volume
μ = viscosity

γ = ratio of specific heats $= \frac{c_p}{c_v}$

R = gas constant

For a perfect gas $c_p - c_v = R$ (in proper units). Therefore from the values given in Figure 2 and the perfect gas law, c_v can be calculated and consequently the ratio of $\frac{K}{\mu}$ for the monatomic gas can be calculated. Among the many assumptions made, we assume that the ionization does not effect the viscosity and thermal conductivity and that the predominant species is monatomic.

Proceeding in this elementary manner,[12] the molecular diameter (d) may be found as follows:

$$Ld^3\approx\frac{M}{\rho_s} \quad \ldots\ldots(11)$$

where

L = Avagadro's number = 6.02×10^{23} molecules/mol
M = Molecular weight
ρ_s = Mass density in the solid state

$\therefore$ for cesium, $d^3 = \frac{132.9}{1.90\times6.02\times10^{23}}$

The relation between viscosity and molecular diameter is given by:

$$\mu\approx\frac{d\rho_s}{13}\sqrt{\frac{3RT}{M}} \quad \ldots\ldots(12)$$

where T is the absolute temperature at which μ is measured, μ is in dyne sec/cm² and R = 8.317 × 10^7 ergs/mol °C.

$$\therefore \mu = \left(\frac{132.9}{1.9\times6.02\times10^{23}}\right)^{1/3} \times \frac{1.9}{1.3} \times \sqrt{\frac{3\times8.317\times10^{7}}{132.9}} \times \sqrt{T}$$

or

$$\mu = .98\times10^{-5}\sqrt{T} \text{ poise}$$
$$\mu = .98\times10^{-3}\sqrt{T} \text{ centipoises}$$
$$\mu = 2.37\times10^{-3}\sqrt{T} \text{ lbs/ft-hr}$$

where T = °K.

To test that the foregoing procedure yields reasonable results, the literature data for CO_2 at 1000°K gives μ = .089 lbs/ft-hr. CO_2 has a density of approximately 1.55 as a solid and a molecular weight of approximately 44.
Therefore

$$d^3 = \frac{44}{1.55\times6.02\times10^{23}}$$

and

$$\mu = \left(\frac{44}{1.55\times6.02\times10^{23}}\right) \times \frac{1.55}{13} \times \sqrt{\frac{3\times8.317\times10^{7}}{44}} \times \sqrt{1000}$$

$$\mu = 3.37\times10^{-4} \text{poises} = .082 \text{ lbs/ft hr}$$

For most engineering purposes the agreement for CO_2 is adequate.

Figure 5 is a plot of μ vs. T and K vs. T. K is derived from the values of γ and c_v given in Figure 2 and the previously mentioned ratio of $\frac{K}{c_v\mu}$ equal to $\frac{1}{4}(9\gamma - 5)$.

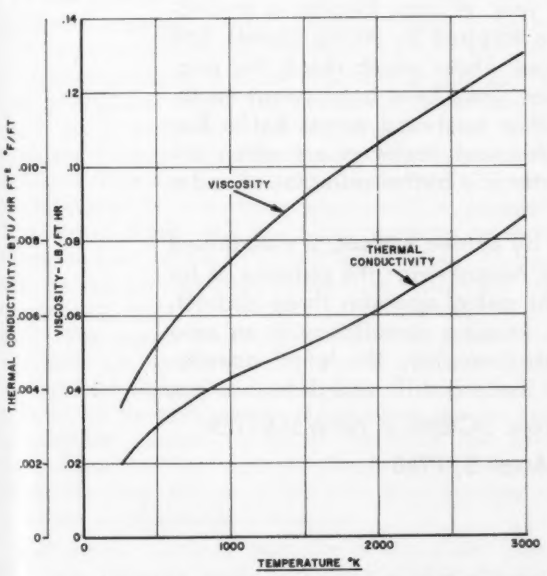


FIG.5 THERMAL CONDUCTIVITY AND VISCOSITY OF CESIUM VAPOR

IONIZATION FROM HEATED PLATES

It is apparent from the previous discussions that the equilibrium ionization of cesium vapor at a given temperature is very low. In order to achieve any reasonable degree of ionization by heating of the vapor, it would be necessary to heat it to a temperature in excess of the ability of present structural materials to contain it. Fortunately, it is possible to achieve esentially 100 per cent ionization of cesium by utilizing an alternate method.

It is a well-known physical principle that certain gases can be ionized by passing them over heated plates of special materials. However, in order for this to occur, it is necessary that the thermionic work function of the plate exceeds the ionization potential of the fluid. Cesium has one of the lowest ionization potentials and positive ions of cesium are readily produced when it is passed over heated plates of tungsten. The tungsten is usually arranged in grid form to present as large an area as possible. Under these conditions it has been found that cesium is 100 per cent ionized in the temperature range of 1500-3200°F.[13] Since the fluid is ionized it can then be accelerated through a potential field. This is the basic principle of the ion engine for space application and cesium is an almost ideal fluid since it has the attributes of having a relatively low boiling point and high efficiency of ionization.

There are, however, two serious drawbacks when using this element (and others) in the ion engine. The ionizing electrode has an extremely short lifetime and the problem of space charge neutralization is still not yet solved. Much work is being done in this field and it is hoped that a major "breakthrough" will occur in the near future.

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Massive icebergs, spawned from the Arctic glaciers, remain a natural hazard which man has not yet learned to control completely. In an average year, about 400 icebergs drift below the 48th parallel into busy shipping lanes off the Grand Banks of Newfoundland. The average iceberg, by the time it reaches Newfoundland, has a volume of 5,000,000 cubic feet, and weighs 150,000 tons. This is about one-tenth the size of the same iceberg in its Arctic birthplace. Also, by the time the iceberg has reached this point, it is two to three years old and is not likely to survive more than a few days longer. The majority of the icebergs originate on the west coast of Greenland. Most of them are formed from some twenty tidewater glaciers in this location. Two mechanisms of iceberg formation are known. In the first, where there is a sharp drop from the shore to the sea floor, the glacier, advancing into the water, is melted below the water line by the ocean as it projects out from the shore. Eventually, the overhang breaks off and falls into the sea. In the other process, where a sloping sea bottom forms the shore line, the advancing glacier pushes into the water, gaining buoyancy as it advances. This buoyant force becomes sufficient to lift the foot of the glacier and snap it off.

About 20,000 icebergs originate each year. A large fraction is grounded in Greenland bays. Another portion is trapped by Arctic islands. Still others ground on the Newfoundland shore. Those which reach the shipping lanes have traveled about 1800 miles. They have been swept northward by the West Greenland Current, then westward across Baffin Bay and finally southward along the Labrador coast. Icebergs are often difficult to detect by radar because sea water is a better reflector of radar waves than ice.

An International Ice Patrol, supported by sixteen nations, is maintained during the ice season—February through August—for the purpose of locating icebergs and warning shipping. The patrol operates three aircraft, an oceanographic ship and two cutters, keeping surveillance in an area about the size of Pennsylvania. The patrol employs the latest oceanographic techniques for the prediction of iceberg drift and deterioration.

—from SCIENCE NEWSLETTER,
March 5, 1960

"THE ENGINEER"

THE ROYAL NAVY TODAY

ACKNOWLEDGMENT
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THE NAVAL SITUATION

WITH LITTLE MORE than two years to run of the 1957 five-year defense plan—which concentrates on measures to prevent, rather than to wage, war—no immediate change is to be expected in the size of our operational fleet. This consists of three aircraft carriers, a commando aircraft carrier and three cruisers, supported by destroyers, frigates and submarines. There is thus little doubt that in the meantime several more wartime vessels will be scrapped. The Royal Navy still has eight wartime cruisers, three or four of which should be sufficient to provide reliefs for the three *Tiger* class cruisers of the operational fleet while refitting or undergoing repair. The seven front line aircraft carriers now available are barely enough to maintain four in the operational fleet, but in accordance with present policy, the wartime carrier *Magnificent* and the hull of another carrier—on which no work has been done since the war—are also likely to be disposed of in the near future, in addition to a number of wartime destroyers and frigates.

All seven carriers and the three *Tiger* class cruisers, however, were laid down during the war and though they have since been reconstructed and modernized, urgent consideration will have to be given in 1963 to a replacement building program. Despite the need to continue our contribution to the Allied deterrent as long as the German problem remains unsolved, Britain must have a larger fleet with modern weapons and power plants, even for a limited war. And large ships nowadays take a long time to build.

By 1963, moreover, rockets in quantity will be supplementing the manned bomber for delivering the H-missile. The solid-propellant naval intermediate range rocket POLARIS is still under development and requires greater range and a warhead with increased explosive power before it will equal the land-based rocket as an effective deterrent. But if, as the Americans believe, both its range and the size of its warhead can be much increased, a seaborne rocket of this type may well prove an equally effective (and certainly much cheaper) supplement to the V-bomber as our contribution to the Allied deterrent. The cost of each of the rocket-launching submarines now under construction in the United States is over £36,000,000 and Britain cannot afford very large sums of this nature for vessels whose sole function is to act as a deterrent. The primary task of the Royal Navy is, directly or indirectly, to defend the sea communications. Ballistic rockets, however, have no recoil and do not require extensive and complicated radar installations to guide them to their target after they are fired, as is the case with anti-aircraft guided missiles. There may thus be no technical reason why some of our new large ships should not be constructed to perform a dual role. Heavy cruisers might be built with a gun armament forward for the defense of the sea communications, with the after plant earmarked for

the stowage and launching of POLARIS rockets. The rockets might well be supplied by the United States under the Mutual Defense Aid Program. Accurate launching in any kind of seaway might prove difficult, however.

None can forecast how long Britain—and Europe—would continue to require imports in the event of an H-bomb war. To judge by the 1957 White Paper, on which our defense plan is based, the British Government believes that it would not be long. Indeed the small contribution which the Royal Navy is making to N.A.T.O. seems further evidence of this view. On the other hand the Soviet Navy of some 300 oversea submarines, thirty-two cruisers and 4000 aircraft would seem purposeless if Russia intends to try and gain her ends by waging war with thermo-nuclear weapons. Is it not more likely that she visualizes that her new policy of bringing the under-developed countries within her orbit might lead to a maritime war fought outside the Continent of Europe, with conventional forces and weapons? This now appears to be the greatest danger facing us. To meet it a strong Royal Navy is essential if the main burden of defending the sea routes is not also to be placed on the United States. It is well to note that S.H.A.P.E. planners not only recognize this danger but admit that N.A.T.O. maritime forces may not be sufficient to deal with it. They plan, however, on the extremely doubtful assumption that if the N.A.T.O. lifeline were endangered by Soviet submarines, we should at once resort to the H-missile—and thus commit suicide. Who would decide when the danger point had arrived? In both world wars it was not reached until we had been fighting for three years.

The cost of the new large ships which must inevitably be built soon will be heavy. A cruiser laid down today would cost ten times that of a pre-war vessel of similar size. But the additional cost of partly arming her with POLARIS rockets would be relatively small. The rockets would be in lieu of the after 6 inch guns, with all the machinery and equipment required to operate them. Moreover it cannot be doubted that, if rocket sites were only to be found in ships, the political agitation against Britain having these missiles would soon die a natural death. In brief, it seems that if the POLARIS seaborne rocket can be developed as an effective deterrent, compared with the land-based BLUE STREAK, we might well consider adopting it at the end of our present five-year defense plan. Meanwhile this review is concerned with the Royal Navy as it is today; and the number, types and performance of our existing ships will be discussed in the following paragraphs in relation to the duties which may be assigned to them under that plan.

THE ROLE OF THE ROYAL NAVY

Before discussing the ships of the Royal Navy, it would be well to note the tasks they would be required to undertake in any war of the future. The Navy's role in time of peace—now more commonly called "the cold war"—has never been in question. By showing the flag in foreign ports, by the appearance of the White Ensign in any area of unrest, the mere presence of a British warship acts as a deterrent to further trouble. Our new frigates, which will before long replace our wartime frigates now used to show the flag in far distant ports, may not be so impressive as the cruiser squadron of pre-war days. Nonetheless they are fine, powerful looking vessels and well able to uphold Britain's prestige in under-developed countries. Nor does anyone need convincing of the Navy's value in limited war—the Korean and Suez campaigns are but two modern examples of the vital part played by the Royal Navy in providing air cover and close support for the Army. Indeed, with the reduction in the number of oversea bases now at our disposal, the Royal Navy's task in limited war is becoming more and more important.

But with Soviet-built submarines and aircraft now available to the Chinese, Middle Eastern and other under-developed countries, our ships must be capable of doing more than merely getting to the scene quickly—they must have modern weapons and aircraft. Three of our seven front-line carriers may well be under reconstruction or refitting or out of action for other reasons. And if some of the remainder are to have their flight decks encumbered with lorries and other heavy equipment required by the troops, as has been the practice in recent campaigns, seven will be insufficient to meet our needs. Finally, a possible major war has to be considered. Despite the arguments of naval enthusiasts who maintain that nuclear attack on this country would still leave millions of people requiring food and other imports, it is generally believed that the Defense White Paper, 1957, presents the true picture. The British people are convinced that no adequate protection can be provided against nuclear bombardment and they question, in these circumstances, the need for imports and for the Merchant Navy and Royal Navy to convey them. Nonetheless there is growing interest in the Royal Navy because of the belief, now held by many entitled to speak with authority, in the possibility of a major war fought with conventional forces and weapons mainly at sea and outside the Continent of Europe. The Royal Navy would in that event be required for its traditional role of guarding the sea communications.

Aircraft Carriers

Britain's last remaining battleship, H.M.S. *Vanguard*, which for the past two or three years has been in reserve and used as an accommodation and training ship, is earmarked for breaking up. The aircraft carrier has thus become the largest and most important fighting vessel in our fleet, though she has not, as is commonly believed, replaced the

battleship as the capital ship. The battleship was designed to fight the most powerful surface vessel which could be employed to gain and maintain control of the sea communications, and the most powerful ship in the Soviet navy is a cruiser. It is thus the cruiser which, under existing conditions, is the capital ship and she must be prepared to protect the carrier from attack by hostile cruisers, particularly when the carrier's own aircraft are engaged elsewhere and not available to defend her. On the other hand, the Pacific operations in the last war showed that the carrier has greatly extended the striking power of maritime forces. Whether in a war fought with nuclear or conventional weapons, she must be large enough to operate aircraft capable of attacking targets in coastal areas, as well as at sea, and to fight land-based defending aircraft whose performance is constantly improving. The Americans indeed have built giant carriers of 60,000 tons—and are building still larger vessels—to supplement or, if necessary, to replace their land-based deterrent power. They are able to operate heavy bombers with a 1000 mile range and are equipped also to fire the 1000 mile REGULUS guided flying bomb. Britain, mainly for financial reasons, is meanwhile awaiting further developments in nuclear power plants before starting a building program to replace her wartime carriers. Though their hulls are old, they have been reconstructed and modernized and, when all have been refitted, will be capable of operating the new strike aircraft N.A. 39—one of the finest low-level strike aircraft yet designed, with a range of action sufficient to attack enemy harbors and war potential factories in coastal areas.

The seventh and latest of the Royal Navy's front-line carriers to be completed is the *Hermes*, launched in 1953, which has now joined the Fleet. She is one of the four *Centaur* class—ships of 22,000 tons with a speed of 28 knots and a complement of forty-five aircraft. The other three are the *Centaur*, the *Bulwark*—in hand for conversion as a commando carrier—and the *Albion*. The *Centaur* and *Bulwark* are, with one cruiser, to provide the main units of our Far Eastern Fleet—deployed east of Suez. All four ships have the angled-deck, the latest type of arrester gear and have been or are being equipped with steam catapults. Though smaller and two or three knots slower than our three larger front-line carriers and, except for the *Hermes*, without the very latest type of radar equipment, they are little inferior to them in the operational role. The 30,000-ton *Victorious* (Figure 1), a pre-war designed carrier, which has been reconstructed and modernized at a cost of £15,000,000, is indeed one of the best equipped carriers in the world, with an air detection and direction system which is a spec-

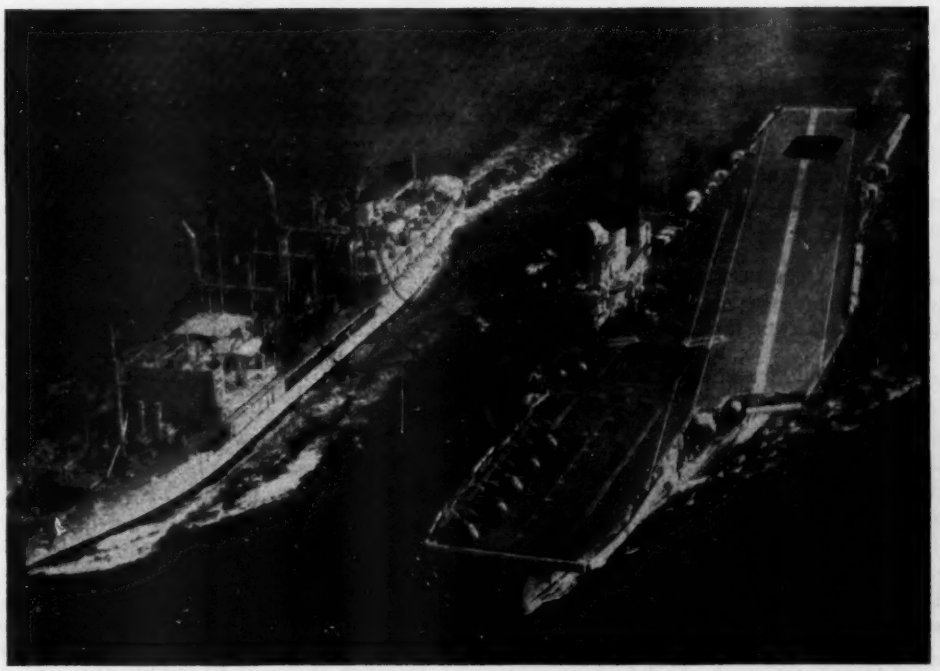


Figure 1. The 30,000-ton carrier *Victorious* refuelling at sea from the R.F.A. *Tide Flow*. Note the fully-angled deck.

tacular advance on that installed in any other carrier. The electronic equipment of the two 43,000-ton carriers *Eagle* and *Ark Royal* is being brought up to a similar high standard. The latter has recently completed an eighteen months' overhaul and refit and the *Eagle* is now being taken in hand. They are 31½ knot ships and can accommodate twice the number of aircraft carried in the *Centaur* class. But for the defense of sea communications they are uneconomical and unnecessarily large, and it would seem that a nuclear-propelled carrier about the size of the *Victorious* would best meet the Royal Navy's future requirements.

Cruisers

No ship has changed her function in a major war more drastically than the cruiser. Until the last war, her function was to act as "the eyes" of the battle fleet and to control the trade routes. Subsequently she replaced the battleship in protecting the carrier from surface ship attack and also assisted the interceptor fighter to counter aircraft attack by providing long range anti-aircraft gun fire. More recently it became clear that for this latter task it was essential to equip ships with anti-aircraft guided missiles and successsive First Lords emphasized that a replacement building program for our cruisers must await the development of these missiles. Despite, however, the powerful cruisers of the Soviet Navy, aircraft attack is regarded as a more serious danger than surface ship attack, and the SEASLUG guided missile has been earmarked for our four new escort vessels of destroyer type. Apart from financial considerations, it seems wise to wait for a cruiser replacement program until the end of the present five-year defense plans in view of the continual progress in weapons and equipment. It may then be practicable to build cruisers with nuclear power plants, to say nothing of the possibility of providing them with a part armament of ballistic rockets for deterrent purposes. It is worth noting in this connection that several of the larger carriers and cruisers of the United States Navy have an additional armament of 1000 mile range REGULUS guided flying bombs. Though these are large missiles and require a good deal of space to accommodate them, they in no way detract from the primary function of the ship—be she a carrier or cruiser. The 28 foot POLARIS rockets are somewhat smaller. They could well be stowed in, and launched from, the after part of a heavy cruiser equipped with a gun and anti-aircraft guided missile armament in the fore part.

Meanwhile Britain has been gradually reducing her cruiser strength. This is in accordance with the present policy of retaining only such vessels as have been modernized and are still effective fighting units, and of keeping them ready for sea at short notice. Five cruisers were earmarked for scrapping in 1958; four more—the *Superb, Euryalus, Jamaica* and *Kenya*—were placed on the disposal list in 1959; and the *Newfoundland* and *Ceylon* have recently been sold to Peru, leaving only eight wartime cruisers, of which H.M.S. *Belfast* (Figure 2)

Figure 2. H.M.S. *Belfast*, of 11,500 tons, is the Navy's largest cruiser. She was completed as long ago as 1939 but has recently been modernized.

is one, and the three *Tiger* class. The *Tiger*, the first of this class, was commissioned at John Brown's Yard, Clydebank, in March. Her 3 inch and 6 inch guns, capable of engaging air or surface targets by visual or radar methods, are not surpassed by the guns in any other navy. She is fitted with a comprehensive gun direction system which enables all her four 6 inch guns, mounted in two twin turrets and equally effective in the surface and anti-aircraft roles, to be controlled by radar. By the end of 1962 we shall be left with only the three *Tiger* class and three or four of the wartime cruisers to replace them during refits. A cruiser is a self-reliant and self-contained fighting unit, capable of steaming at high speed in rough seas. It is true that her reconniassance function has largely been taken over by the aircraft carrier. But she is a particularly valuable fighting ship in all forms of war. Unless, indeed, it is suggested that the H-bomb has ruled out war at sea, or that we are to rely entirely on the United States, it is difficult to see how even the Royal Navy can deal with thirty-two Soviet cruisers with only the three *Tiger* class.

Destroyers, Frigates and Lesser Vessels

The destroyer's function has also been changed by the elimination of the battleship, though a formation of these vessels may well still be used to attack a carrier at night. Under modern conditions, however, protection for both the Fleet and merchant ships against underwater or air attack is the main consideration. Thirty-three of the 110 wartime destroyers remaining in 1951, when the rearmament program began, have in fact been converted to fast anti-submarine escort frigates and there are now building four fleet escort vessels of destroyer type whose main task will be to provide anti-aircraft defense with the SEASLUG guided missile. A notable feature of these four ships is their combined gas turbine and steam turbine propulsion which, when steaming at sea, will enable them to double their available horsepower at a moment's notice. To ac-

commodate the SEASLUG missile and the extensive and complicated installations required to guide them to their target, a larger vessel than the conventional destroyer is required. From the scale model the new fleet escort vessels look more like small cruisers of between 4000 and 5000 tons. But with six more destroyers earmarked last year for disposal, the Royal Navy, even with these four new vessels, will only have fifty-three destroyers available—including the eight fine *Daring* class completed since the war—as compared with 150 modern Soviet ships of the same type. Most of the latter are powerful vessels, armed with four 5 inch guns and eight to ten 21 inch torpedo tubes, with a speed of 36 to 38 knots. How many destroyers shall be built in the future is anybody's guess. But the day is now over of the relatively small destroyer armed with guns; her anti-submarine function and "maid-of-all-work" duties have now largely been taken over by the anti-submarine frigate.

Britain has certainly done well by N.A.T.O in providing during the past few years a substantial number of first-rate frigates and minesweeping vessels, though it is significant to note that most, if not all, of these ships were ordered or projected before the new defense plan of 1957. By the end of this year, thirty-three of the forty-four new frigates authorized under the rearmament program will have joined the fleet. Included in the forty-four are five aircraft direction vessels (Figure 3) to give

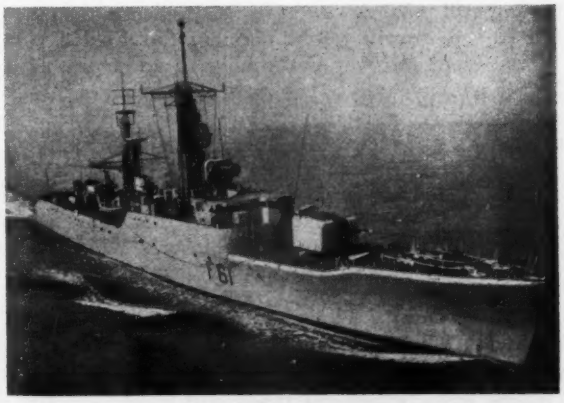


Figure 3. H.M.S. *Llandaff*, of 1730 tons, is an aircraft direction frigate. She was completed in 1958.

carriers early warning of approaching air attack; four frigates with a powerful anti-aircraft armament of four 5 inch guns in twin turrets (Figure 4), to provide anti-aircraft protection for merchant ships; and seven general purpose vessels capable of carrying out both these duties, besides their primary task as anti-submarine ships. These last will carry a helicopter and, like the four new fleet escort vessels, will have combined gas turbine and steam turbine propulsion. All R.N. anti-submarine frigates—including those converted from destroyers—are being fitted with the latest and greatly improved detection and classification equipment and with the new anti-submarine "homing" torpedo. Meanwhile, in accordance with present policy, an increasing number of 19-knot wartime frigates are being sold or scrapped year by year, though some will still be required for a few years for "showing the Flag."

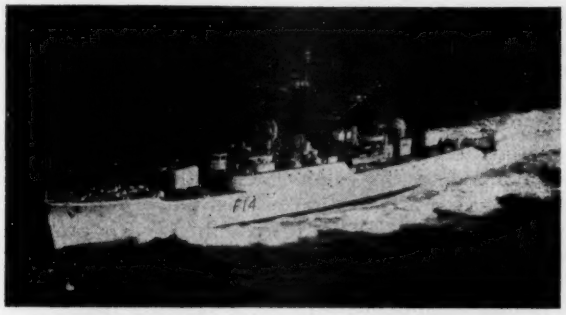


Figure 4. H.M.S. *Leopard*, of 1738 tons, is an anti-aircraft frigate. She was completed in 1957.

The current Navy Estimates show a total strength of 232 minesweepers of a new type, only two or three of which still remain to be completed. Their hulls are constructed mainly of non-magnetic material and they are intended to deal with all types of mines—contact, magnetic and influence. The larger, or coastal, type will operate in shipping channels near the coast; the smaller, or inshore, type are for sweeping estuaries and other shallow waters (Figure 5). Both are diesel driven. Though all are of recent construction, the vast majority have necessarily to be kept in reserve, and it might well be in N.A.T.O.'s best interest if the smaller powers took over a number of these vessels. If they assumed greater responsibility for minesweeping in the Channel and North Sea, it would release British naval personnel and resources for larger ships at

Figure 5. H.M.S. *Chelsham*, of 120 tons, is an inshore minesweeper. She is propelled by two Paxman diesel engines.

the outbreak of war. The Royal Navy has also some twenty-seven wartime ocean-going minesweepers whose original function was to sweep ahead of the fleet. But, as in the case of other wartime vessels, they are gradually being disposed of. Finally there are eighteen recently constructed seaward defense craft for detecting submarines in the approaches to defended ports and a dozen fast patrol craft—with four more building. A few of these craft are still used operationally and for training, but the coastal forces which did such brilliant work in the last war are now maintained only on a skeleton basis.

THE NAVIES OF THE COMMONWEALTH

Despite the anxiety of some of the Commonwealth countries to avoid taking sides in the cold war, there is little doubt that N.A.T.O. would have the full co-operation of the whole Commonwealth in the event of a major war. The post-war period has witnessed a substantial increase in the Commonwealth navies and this development has been greatly assisted by the transfer of ships, in the form of gifts, loans or sales, from the Royal Navy. Moreover, some of the Dominions have new ships under construction in British yards. Two frigates are building for the Royal New Zealand Navy, two frigates for the South African Navy—which has already received six coastal minesweepers and two seaward defense vessels originally intended for the Royal Navy. The Indian Navy has ordered six new frigates, two of which are already completed, and has bought the carrier *Hercules,* now being modernized, and three *Hunt* class frigates. The Pakistan Navy has two Royal Navy destroyers under conversion as anti-submarine frigates and has bought another wartime destroyer. Seaward defense vessels and coastal and inshore minesweepers have also been transferred as gifts to the Royal Malayan Navy, the Nigerian Navy and the Royal East African Navy.

THE SUBMARINE AND ANTI-SUBMARINE SITUATION TODAY

Submarine

In a debate in the Commons early last year on the Navy Estimates, the Parliamentary Secretary, Admiralty referring to the voyage of the *Nautilus* under the North Pole in 1958, said "it is now recognized that nuclear-powered submarines represent a major scientific break-through." This remark was made five years after the *Nautilus* went to sea, three years after she had steamed 60,000 miles on about 8 pounds of nuclear fuel (much of the distance submerged) at speeds "of between 15 and 20 knots," and with the knowledge that the United States had twenty-nine nuclear-powered submarines built, building or authorized. Six months ago, the Duke of Edinburgh spoke even more emphatically when he "laid the keel" of the first British submarine of this type, the *Dreadnought.* "The atomic submarine," he said, "expensive though it may be, places in our hands a weapon whose wide development possibilities make it of infinite value to our protection and prestige." Every expert in submarines, or in naval tactics will agree wholeheartedly with these views. But is anything being done to convince the taxpayer who has to foot the bill? "How is it," he asks, "that the nuclear-powered submarine—so we are officially informed—can dive 'below 400 feet,' when conventional submarines in the first world war were forced by depth charge attack below that depth and still survived?" "How is it that official reference is made to a submerged speed of 'up to 20 knots' when fifteen years ago the Germans were building a submarine which, they claimed, could proceed at 25 knots submerged for 150 miles?" He has in mind that the performance of the British experimental submarine, *Explorer,* with engines based on the German model, seems to prove that the German claim was justified. Finally, he asks, "Now that we have full access to the technical knowledge and practical experience acquired by the United States—which, if words have any meaning, has recently built a nuclear-powered submarine that is very much faster than the *Nautilus*—why are we content to lay down only one of a similar type?"

The answer is, of course, primarily, lack of finance. Britain still has to take her share in preventing war which is absorbing a substantial and increasing part of our defense budget. Moreover the feeling still persists—even in the highest quarters—that the deterrent might possibly fail to deter, in which event the war is unlikely to go on for long. Lastly we have still to complete a program of diesel-electric drive submarines planned some years ago when we were concentrating our nuclear knowledge and resources on the building of nuclear power stations. They are first rate conventionally powered submarines, and we may be sure that they are a great improvement on the German type XXI, which were in Allied hands after the war and which have a submerged speed of 16-17 knots for one hour and of up to 5 knots for four or five days. There are to be thirteen of these submarines—eight *Porpoise* class and five similar but improved vessels of the *Oberon* class. Eleven of these will have joined the Fleet by the end of this year. All are fitted with both air and surface warning radar which can be operated also at periscope depth. They are equipped with air conditioning and sea water distilling plants and have oxygen replenishment and carbon dioxide and hydrogen eliminators, thus providing for a submerged patrol of several days. It would be a great mistake to scrap this submarine building program even if it were financially possible to do so. For patrolling and operating in waters controlled by the enemy—the original and still very important function of a submarine—they could scarcely be bettered.

Nonetheless it is essential to realize that nuclear propulsion, while giving the surface warship almost unlimited endurance at high speed and many other advantages, has revolutionized the submarine. It has changed her from a relatively cumbersome and slow-moving craft—which, however, nearly brought this country to her knees in the two world wars—into a submerged vessel which is as fast and as maneuverable as a fast surface ship. It is clearly desirable for security reasons that her maximum speed should for as long as possible be concealed from potential enemies. But from our knowledge of the submerged performance required of submarines today and of the speeds they have already attained, it is clear that "up to 20 knots" is a considerable understatement. Speeds of 25 knots may be regarded as the normal maximum, with speeds of 5 or even 10 knots higher with specially designed hulls. Though nuclear-powered submarines may be designed for some particular task—such as radar picket duty—they fall broadly into three types. The normal patrol submarine; the very fast "hunter-killer" submarine with a specially designed hull; and the large guided missile or still larger ballistic rocket-launching submarine. As stated above, Britain will soon have thirteen new conventionally-powered submarines, eminently satisfactory for carrying out a submarine's normal duty of patrolling in enemy waters. A flotilla of these patrol submarines is now to be based on Singapore. The rocket-launching submarine would certainly be of great value to the Soviet navy for bombarding industrial areas and towns, and the United States is now building nine of this type in the belief that developments will give the naval rocket POLARIS a range of 1500 miles. Launching their rockets unexpectedly in the vicinity of an enemy's coast, they should provide the N.A.T.O. nations with the most effective possible deterrent.

But the cost of each submarine of this type now building in the United States is estimated at £36,000,000 and Britain just cannot afford this large sum for a vessel whose sole function is to provide a deterrent. The Royal Navy's primary duty is the defense of the sea communications, which makes the "hunter-killer" submarine one of our most urgent requirements. Rocket-launching submarines—and indeed any other type of submarine equipped with "homing" torpedoes—will not deliberately come within range of a surface asdic vessel. The most effective method of locating and destroying them is for another nuclear-powered submarine to patrol submerged. She must be fast and relatively small, armed with homing torpedoes and equipped with the latest and improved type of asdic and hydrophone installations. It is thus highly satisfactory that Britain is hastening the construction of the *Dreadnought* by purchasing a complete power plant and propulsion machinery similar to those installed in the United States submarine *Skipjack* commissioned just over a year ago. The propulsion plant is being made available to Rolls-Royce and Vickers-Armstrongs, the firms which are combining in the design and construction of the *Dreadnought*. The latter's hull is also being based on the *Skipjack's* hull, which in turn is based on the hull of the experimental United States submarine *Albacore*—conventionally powered and completed in 1953. This hull has the form of a whale with a rounded instead of a flat-topped deck and with the bow diving planes transferred to the conning tower (or "sail" as the Americans call it, because it is shaped like a fish's dorsal fin). Despite her conventional power plant, the *Albacore* is credited with a submerged speed in excess of that of the nuclear-powered *Nautilus*. The "marriage" of an *Albacore* hull with a nuclear power plant has given rise to fantastic reports of the submerged speed of the *Skipjack* class. In any event they are much faster than the *Nautilus*, and it would not be surprising if their speed was at least 35 knots. The surface displacement of the class varies between 2300 and 3000 tons and they have only one shaft with a five-bladed propeller. Their reactors are similar to the *Nautilus* plant but embody major improvements in design, including a simpler method of core-changing. It is much to be hoped that Britain will not delay in building a flotilla of these submarines on the ground that we must have proof of the success of the *Dreadnought*. They are the kind of vessels most urgently required by the N.A.T.O. nations.

Anti-Submarine

As emphasized a year ago in our review of the Royal Navy, the problem of anti-submarine defense primarily depends for its solution on increasing the range of detecting devices. Indeed the major share of the money allocated for naval research and development is earmarked for the improvement of measures to detect and destroy an enemy below and above the surface of the sea. Our new anti-submarine vessels will have an asdic installation with a performance five times better than those now in use. Plans have been made to fit this equipment in all modern frigates and other anti-submarine vessels at present in service. The new homing torpedo—literally a self-guided missile—will also be installed in all these ships and in anti-submarine aircraft. Apart from the serious threat to an island people implicit in the immense Soviet submarine force, we have now to be prepared to deal with the submarine in a limited war. The Chinese Communists already have twenty of these vessels and the United Arab Republic nine. The Soviet Navy is known to have several missile launching submarines and when reinforced by more modern, nuclear propelled underwater ships, with their silent running engines, it will be extremely difficult to locate them. During the past year the policy of streamlining and concentrating naval shore establishments wherever

practicable has brought together at Portland both the new Underwater Weapon Establishment and the Underwater Detection Establishment. This is achieving a marked improvement in efficiency in anti-submarine research, development and training. Together with the flotilla of fast submarines and modern anti-submarine vessels at Portland—to which a helicopter flying school has now been added—for the training of the Navy's anti-submarine personnel, the proximity of these two establishments will lead to a valuable cross-fertilization of scientific and naval ideas in the undersea warfare sphere.

Little information is available regarding the performance of the devices for detecting submerged submarines. But in general it may be said that, as radar cannot detect a submerged vessel, research and development are being concentrated on improving the measures used in World War II—asdics, and also the hydrophone which the Germans had already brought to a high state of efficiency before the war ended. It seems hardly necessary to point out that a relatively small, fast nuclear powered submarine patrolling submerged could employ both these measures to her own advantage. The practicability of operating helicopters from small ships is also a great advance. With their ability to hover, they are ideal for the employment of the sonobuoy —which, with the aid of a hydrophone, picks up and transmits to ships or aircraft in wireless contact the noise of a submarine's propellors. Dipping asdics can also be lowered from helicopters to transmit back echoes from a submarine to the operator above.

Improvements in devices for destroying a detected submarine have kept pace with the improved performance of detection measures. The most formidable weapon is the atomic depth charge designed for dropping from an aircraft or helicopter. As yet, however, there have been no reliable reports that this weapon can be adapted for use by surface ships, having regard to the safety factor required. Another effective weapon is the homing torpedo which can be fired from a surface ship, aircraft or patrolling submarine. And, finally, there is the post-war designed three-barrelled anti-submarine mortar which is "married" to the asdic set. Controlled electronically, the three mortar bombs are fired automatically in a pattern and aimed at the position where the submarine is expected to be when they explode. But in concluding this section, it must be emphasized that the main problem is to locate a submerged submarine at any depth down to 1000 feet. Missile launching submarines and indeed any submarine with a homing torpedo will do their utmost to avoid coming within asdic range of an anti-submarine surface ship. Without being unduly pessimistic, one would perhaps do well to take note in this connection of the present position as seen by Admiral Cooper, Commander of the U.S. anti-submarine defense force. "What is urgently needed," he says, "is a technological breakthrough to permit an aircraft to scan 50 to 75 miles of ocean at a time down to a depth of 1500 feet. Present methods of detection fall so far short of this that the U.S. Navy has been forced to throw nearly every type of unit that floats or flies into the detection effort."

THE FLEET AIR ARM

The 30,000-ton aircraft carrier *Victorious* completed over a year ago—a pre-war designed carrier entirely reconstructed and converted into one of the finest medium-size vessels of her type—has had a busy year working up to full operational efficiency and carrying out exercises and trials with the Royal Navy's new generation of aircraft. Her own squadron of "Scimitars"—the first to be embarked—has given every satisfaction in N.A.T.O. exercises, particularly in regard to the rate of climb of this aircraft. The Vickers-Armstrongs "Scimitar" is the Navy's latest fighter—a single-seat twin-jet strike fighter capable of delivering tactical A-bombs or of employment as an interceptor or reconnaissance aircraft. Powered by two Rolls-Royce "Avon" engines, it is able to sustain air speeds well above Mach 1 at sea level. Power controls are fitted and "blown flaps" reduce the safe approach speed for deck landing. After extensive night landing and take-off trials in the *Victorious* early last year, the de Havilland "Sea Vixen" also entered operational squadron service with the commissioning of No. 892 Squadron at Yeovilton in July. These two-seat day and night all weather fighters are to replace the "Sea Venom" as the Navy's all-weather fighter. Powered by two Rolls-Royce "Avon" turbojet engines, they have an armament of FIRESTREAK infrared air-to-air guided missiles and twenty-eight 2 inch air-to-air rockets in two batteries carried internally on retractable racks in the bottom of the fuselage.

The Navy's new strike aircraft—the Blackburn NA39—made its first appearance at sea last year by carrying out several landings and take-offs in the *Victorious*. Powered by de Havilland "Gyron Junior" engines, the NA39 is believed to be superior to any aircraft in the world in its specialized role of a low-level strike aircraft. Some time must elapse before these machines are in operational service, but the output up to date is well within the terms of the Ministry of Aviation contract schedule. The Fairey "Gannet" early warning A. E. W. Mark 3 is another new aircraft which meets one of the Navy's more urgent requirements. Early warning aircraft greatly increase the range of the ship's radar in detecting impending aircraft attack, the picture on the "Gannet's" screen being reproduced by radar link on the ship's screen and thus acting as an airborne intelligence center. For anti-submarine duties, however, the earlier "Gannets" are likely in due course to be replaced by the helicopter, which can now be

operated from most types of ships and, because of its ability to hover, is vastly superior to fixed-wing aircraft for anti-submarine work. The production order for the gas-turbine-powered Westland "Wessex" indicates the importance which the Admiralty attaches to the helicopter, despite the temporary withdrawal from service recently of the Westland "Whirlwind" Mark 7, due to engine trouble. An interesting and highly successful series of trials has been carried out in recent months with the lightweight Saunders-Roe "Wasp" as an anti-submarine helicopter operated from the sterns of ships of frigate type. The importance of the helicopter for submarine work was emphasized by the then Parliamentary Secretary, Admiralty, in the debate on the Navy Estimates, when he referred to the opening, at Portland, in April last year, of the first Service helicopter airfield in the United Kingdom. In the same debate the introduction was announced of a new scheme for the entry of Fleet Air Arm helicopter pilots. Young men who wish to serve in that capacity and have the necessary qualifications will be given special five-year commissions on the Supplementary List of the Royal Navy—age limits on entry 17 to 23 years. Britain's seventh front line carrier—H.M.S. *Hermes*—recently completed and commissioned—is a modernized version of her 22,000-ton sister ships *Albion, Centaur* (now equipped with two steam catapults) and *Bulwark,* which is under conversion as a Commando carrier.

RESEARCH AND DEVELOPMENT

The Royal Navy's research and development programs continue to have as their primary aim the improvement of measures for locating and destroying submarines and aircraft. The new asdic installations have a performance five times better than those at present in use in the Fleet and the introduction of helicopters—which can now be operated from most types of ships—is making the anti-submarine forces more effective and flexible. The gas turbine "Wessex" helicopter is already in production for naval use. On the anti-aircraft side, automatic means are being developed for handling tactical information received from radar warning and electronic data in our air defense systems. A small surface-to-air guided weapon—the SEACAT—is also under development to replace the 40mm gun throughout the Fleet and the missile is now undergoing tests. Meanwhile, H.M.S. *Girdle Ness*—the guided weapons trials ship—after recommissioning, sailed in June for Malta to carry out further trials in the Mediterranean of the medium range anti-aircraft guided missile SEASLUG. In the field of engineering research, naval engineer officers, scientists and industry, working as a team, have been concentrating on propulsion machinery which will give ships increased endurance along with reductions in the weight and size of machinery, thus providing more space for weapons and equipment. A notable advance has been made with the Royal Navy's new general purpose frigates which, like the four new guided missile destroyers, are to be equipped with a combined steam turbine and gas turbine plant. The proportion of the weight of these ships devoted to weapons and associated equipment has been increased from 15 to 25 per cent. At the same time, the greater efficiency of the new machinery has increased the frigate's endurance by 25 per cent—equivalent to a saving of more than £250,000 on fuel costs during the ship's life.

With the purchase of a complete nuclear power plant and propulsion machinery for the submarine *Dreadnought* from the United States and the access gained to American practical experience of nuclear propulsion power plants, every effort is being made to design an economic nuclear merchant ship. The Marine Nuclear Propulsion Committee, under the chairmanship of the Civil Lord of the Admiralty, is examining designs for nuclear propulsion plants submitted by the Atomic Energy Authority and several British nuclear engineering firms. All these systems possess different characteristics in terms of weight, size, capital and operating costs and other technical factors and not all of them are equally advanced for use in surface ships. Concurrently under examination are methods of financing the first ship and the problems of safety in the nuclear ships themselves and at their ports of call. A new chair of Nuclear Science and Technology has been established at the Royal Naval College, Greenwich, which is responsible for the advanced scientific and technological education of naval and Admiralty civilian officers. Courses are being held for design specialists, technical officers and commanding officers and others of the seaman specialization. With a view to investigating the behavior, under high rates of loading, of the various steels and welded joints used in warship construction, the Admiralty has installed a large impact machine at the Naval Construction Research Establishment, Dunfermline. It is capable of delivering 500,000 foot-pounds of energy to a test specimen and though intended primarily for application in the building of warships, it is expected to be of value in other branches of engineering and to steelmakers.

Though the Royal Navy is now officially credited with having the "homing torpedo," it is necessary to study authoritative reports from the United States to ascertain new developments on the material side. The guided power bomb, it appears, is by no means the exclusive property of the air forces. The air-to-surface guided missile BULLPUP is now in operational service with United States naval aircraft squadrons. It is a missile of 540 pounds, 11 feet long and 1 foot in diameter, has supersonic speed with a 250 pound non-nuclear warhead. The BULLPUP is the sixth guided missile—including the surface-to-surface REGULUS—to become operational in the United States Fleet. A new navy all-weather jet

fighter with a speed twice that of sound is also in production for delivery to the United States Fleet this year. Launched by catapult, it will be capable of landing on less than 300 feet of aircraft carrier deck. Another interesting development is a super-sensitive television camera to indicate faint particles of light in the dark ice above, when a submarine is proceeding under an ice field. It was used by the *Skate* in her voyage under the North Pole to enable her to spot areas of thin ice through which she could safely surface. The U.S. Department of Defense has announced that this television system has capabilities for night viewing far beyond any previously achieved.

Curtiss-Wright Corporation has released some information on a new type of internal-combustion engine which is neither a gas turbine nor a reciprocating engine. Actually, it is a rotating combustion engine with a 4-in-thick triangular piston that rotates, rather than moving up and down. It is impelled by the explosion of a mixture of gasoline and air in the surrounding oblong casing, similar in shape to that for a Roots blower. The triangular piston, which appears solid but is probably hollow, is the only moving part other than the crankshaft. The piston rotates in an eccentric course, furnishing the equivalent of a 3-cyl, 4-cycle gasoline engine, and is always in contact with the seals between it and the casing.

An automotive carburetor supplies a mixture of gasoline and air into the engine chamber through a side wall port. As the engine's rotor turns, the mixture is compressed and fired by a single sparkplug. The exploding gases deliver the power to the crankshaft through the rotor. Exhaust fumes escape through another port. There are three power sequences per revolution to the crankshaft, maintaining an almost continuous intake, compression, ignition, expansion, and exhaust cycle.

Absence of reciprocating parts tend to eliminate vibration and insure smooth operation because of complete balance attained. The engine does not require premium fuels and operates at high efficiency on automobile gasoline at fuel consumption of 0.45 and lower. The noise level also is low. . . .

While no price range was given for the new engine, it was said that it would be low in cost because of its simplicity and absence of exotic materials. The lack of "hot parts," such as exhaust valves and turbine blades, minimizes the use of expensive metals.

The new engine will be produced by the Wright Aeronautical Division at Wood-Ridge, N. J., with various components supplied by other Curtiss-Wright divisions.

—from MECHANICAL ENGINEERING
January, 1960

HENRY W. PHILLIPS

THE EVOLUTION OF A NATIONAL DEFENSE WEAPON SYSTEM

ACKNOWLEDGMENT

This article written by Henry W. Phillips, Manager, BMEWS Operations Administration, Radio Corporation of America, Moorestown, New Jersey, is published as of timely interest to readers of THE JOURNAL.

APPROXIMATELY 80 per cent of the products and services furnished to present-day weapon systems by the electronics industry were not available as recently as 10 years ago. This is not surprising when we consider the evolution of the weapon system concept and the rapid development of new electronic and mechanical components. Only since the early days of World War II have we seen the results of advanced development and application of such techniques and equipments as jet propulsion, nuclear and thermonuclear weapons, atomic power, missiles, satellites, automatic fire control systems, digital computers, automatic displays, automatic checkout equipment, and many others.

During World War I, weapon systems, as we now interpret the term, were unknown. Officers evaluated battle situations and issued orders to men who took action with manual weapons—rifles, bayonets, machine guns, and artillery. As a result, military operations were slow and inefficient by our present standards.

Shortly before and during World War II, techniques and equipment were refined so that effective electronic weapon systems became a reality. The first such system involved antiaircraft weapons. Antiaircraft guns were controlled manually or semi-automatically, based on information obtained from sound and optical trackers, search-lights, computers, and gun directors. Unfavorable weather seriously hampered operations, however, and search-lights revealed the position of antiaircraft units. The development of radar radically changed the system. Detection became possible under all weather conditions and at ranges of several hundred miles. The next step electronically united the radars, computers, and guns for accurate fire control. This, then, was a simple integrated weapon system.

Many other achievements occurred during World War II that led to complex weapon systems: advanced jet aircraft engines were developed; guided missile work began; advanced fire control systems were developed for ground, shipboard, and airborne applications; and nuclear energy was harnessed as a weapon and as a source of power.

Since the end of World War II, some of the greatest advances in the defense program have been accomplished in the electronics field. Radars, computers, and communication equipment have been greatly refined. Transistors, printed circuitry, and microminiature modules have contributed tremendously to our superior electronic equipment. Undoubtedly, the development and application of miniaturized electronic components is helping us to maintain our position as a world leader in perfecting weapon systems.

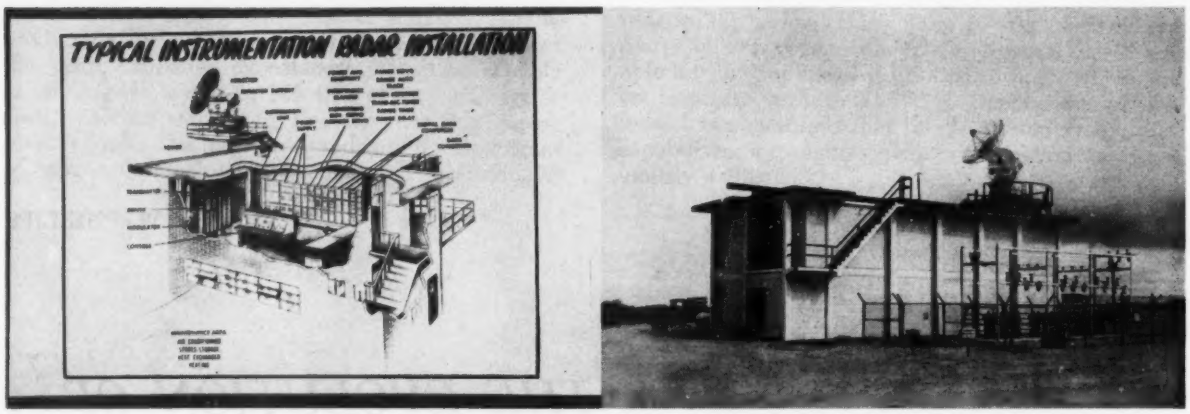


Figure 1. Precision Instrumentation Radar—the most accurate of its type ever developed.

This type radar is being used at many U.S. missile test ranges including the White Sands Missile Range and the Cape Canaveral Range, to track missiles during test flights. This radar can also be adapted to serve as a flexible surveillance radar by scanning through a selected sector to provide desired coverage.

The installation at Grand Bahama Island is shown. This is one of a series of such stations to record information on missiles fired from the launching area at Cape Canaveral, Florida. The radar automatically locks on to a missle and accurately tracks it during its test flight. Precise data on the performance of the missile is recorded and made immediately available in useable form without time-consuming data reduction work.

A specific development by the Radio Corporation of America in recent years has been the "Bumblebee" precision tracking and guidance radar. The radar was the result of a program that RCA undertook shortly after World War II for the Applied Physics Laboratory of Johns Hopkins University. Tests on the equipment proved that its extreme accuracy made it suitable as a precision tracking and guidance radar for guided missile systems. "Bumblebee" then became the forerunner of several high-accuracy radars.

Figure 1 illustrates such a radar (AN/FPS-16) that has been used in tracking missiles during test flights. Data obtained from tracking the missiles are recorded in such form that they can be used immediately without extensive, time-consuming data reduction and analysis. The Naval Research Laboratory has found this radar to be the most accurate of its type ever to be developed.

This and similar instrumentation radars have been ordered for use at many United States missile test ranges, including Cape Canaveral, White Sands Missile Range, Naval Air Missile Test Center at Point Mugu, and Naval Ordnance Test Station. The radars could also be adapted to serve as flexible surveillance radars by scanning through a selected sector to provide desired coverage.

Another example of the application of precision radar can be found in the tracking radar of the TALOS Defense Unit. The radar is installed in an evaluation system at White Sands Missile Range to track and illuminate targets during system operation.

The TALOS Defense Unit was originally conceived for the Air Force, developed by RCA, and installed in 30 months at White Sands as an evaluation unit. Now operated by the Army, the unit includes two tracking and illumination radars, four guidance radars, two missile launchers with missile magazines, and support equipment.

During system operation, the only necessary personnel are in the Fire Control Room depicted in Figure 2. The operators in the room merely monitor the system's operation during the fully automatic mode of the system. The human-engineered con-

Figure 2. Fire Control Center of the Talos Defense Unit—the first fully automatic missile system which was designed to engage and shoot down enemy targets automatically based on data from a remote source. The operators in the room merely monitor the system's automatic operation. They can by manual or pushbutton controls inject elements of human judgment if they deem such action to be necessary.

soles permit constant monitoring and immediate action to inject elements of human judgment by the operators if they deem such action to be necessary. The automatic mode permits automatic target acquisition and destruction. Tests on target drones have revealed that automatic operation of the system provides high fire power, great accuracy, high kill probability, and excellent reliability. With its automatic checkout equipment, the system can be checked out in about 15 minutes, whereas normal checkout would require several hours. Figure 3 shows the firing of a TALOS missile from the Defense Unit at White Sands during an evaluation study.

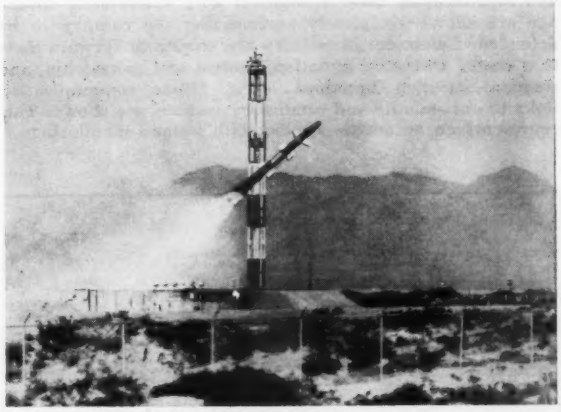


Figure 3. Automatic firing of a Talos missile from a test installation at White Sands Missile Range during an evaluation test. The complete system has the capability of automatically engaging a multitude of targets in different directions simultaneously. This "shoot" resulted in a direct hit against a target far down range.

On major weapon systems, several defense contractors usually support one another in perfecting the system. RCA has performed such a subcontractor role for CONVAIR on the ATLAS missile program. Figure 4 shows a mock-up of the ATLAS Control and Checkout Center being developed by RCA under a subcontract from CONVAIR. This room will be the nerve center of the fire control and automatic checkout equipment being produced by RCA for the ATLAS missile.

Early in 1958 the Air Force announced that RCA has been designated as weapon system contractor for the design and construction of a Ballistic Missile Early Warning System (BMEWS). Because of the development of ICBM's, it has become necessary to construct a high-power, long-range radar system with a series of forward sites at northern locations to detect any enemy ICBM's that may be launched toward the United States or Canada. Figure 5 is an artist's conception of a forward site with detection and tracking radars and support

Figure 4. Atlas Checkout and Control Center. This represents the nerve center of the fire control and automatic checkout equipment for the Atlas missile.

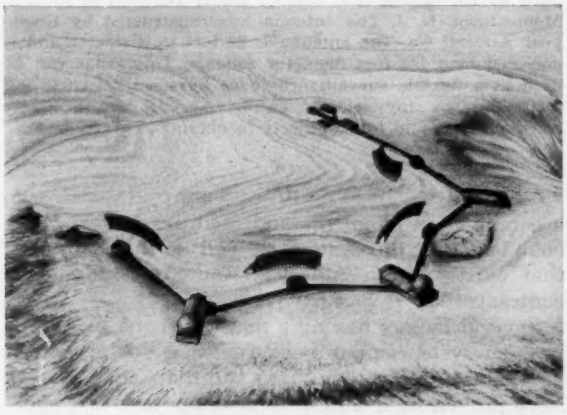


Figure 5. Typical BMEWS Northern Site. A combination of high power, long range, surveillance and tracking radars are used to provide complete coverage and positive identification of any attacking ICBMs. Highly reliable performance is assured by using radars of these types.

buildings. Figure 6 shows a typical tracking radar with radome partially erected. A polar projection immediately reveals why the forward sites are to be located in northern regions; the shortest missile trajectories from the USSR to the United States are across the polar area. Typical approximate distances to principal U.S. cities include 3000 miles to Los Angeles from Siberia, 4000 miles to Chicago from Siberia, and 4500 miles to New York City from northwest Russia. All of these distances are within the range of present ICBM's.

In developing BMEWS to warn of ICBM attack, RCA is supported by several major subcontractors, including the General Electric Company, Sylvania Electric Products, and the Goodyear Aircraft Corporation. Rearward communications are being supplied by Western Electric Company under separate Air Force prime contract. Construction will be accomplished by U.S. Army Corps of Engineers. Such

Figure 6. BMEWS precision tracking radar with radome partially erected. This long range radar system was developed by the Missile and Surface Radar Division of RCA at Moorestown, N. J. The antenna was constructed by Goodyear Aircraft Co. The antenna is 84 feet in diameter and is enclosed in a 140 feet diameter radome. This radar can be used as a flexible surveillance radar by scanning back and forth through any selected sector. Also, it can precisely track missiles and other objects to obtain accurate data.

a combination of talents and facilities indicates the complexity of the system as well as the teamwork that exists within American industry on defense contracts.

Several factors having a major bearing on future weapon systems have been revealed during recent years. First, private industry and the Armed Forces have proven their ability to develop, test, and operate fully automatic advanced weapon systems. Second, jet engines and rocket motors have provided vehicles with speeds up to Mach 20 so that ICBM speeds of 15,000 miles per hour can be expected. Third, advanced electronic techniques have rapidly improved tracking and detection radars, automatic data transmission and communication links, miniaturization, and automatic checkout equipment.

A future defense system, based on the above factors, involves several special considerations. (1) An extremely short time would occur between the first warning of an attack and completion of the attack. This time can be estimated to be less than 30 minutes. (2) The short time would limit human action and necessitate a completely automatic defense system. (3) Human action would be limited to observing and monitoring the automatic system performance with push-button over-ride controls. (4) The system must operate continuously and must be self-checking.

The basic functional requirements of an advanced defense system include detection and identification, communication, centralized monitoring and control, computation, weapon selection, and weapon action. All of these functions, except monitoring, must be

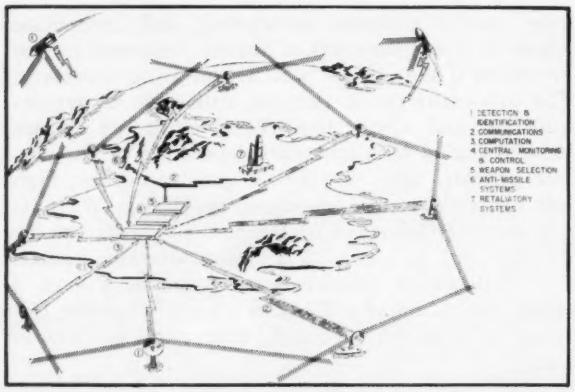


Figure 7. Diagram of Defence System Concept. Detection and identification radar equipment with overlapping coverage are shown completely surrounding the country to be defended. Communication links are shown to forward data to a center where computation, control and monitoring, and weapon selection functions occur. Other communication links to anti-missile and retaliatory systems are shown. This represents an automatic system with human monitoring.

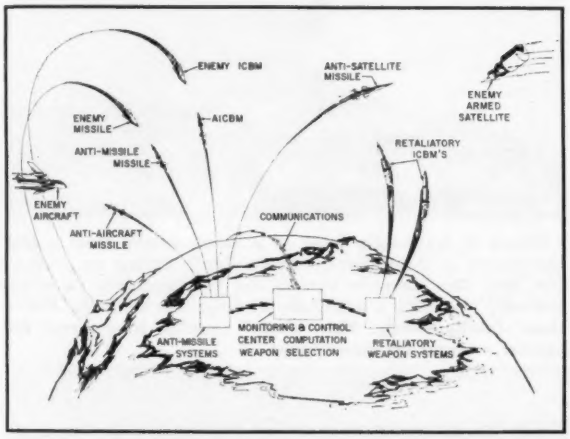


Figure 8. Defense System in Operation. For defense against an ICBM attack, three events must occur in a matter of minutes: (1) The attack must be positively detected at an early stage; (2) Defensive action must destroy enemy vehicles before they destroy their targets; (3) Retaliatory action must neutralize enemy bases to prevent further attacks. This illustration shows an automatically coordinated defensive and retaliatory battle under close human monitoring.

automatic. While the monitoring will be performed by human beings, the monitor displays will be automatic.

Figure 7 shows a simplified diagram of a theoretical defense concept. Detection and identification equipments with overlapping coverage are located on the periphery of the area to be defended. These equipments consist of extremely high-power, long-range, high-capability radars which may be supplemented by surveillance satellites. Communication links connect these outposts to a central point con-

taining computation equipment, central monitoring and control, and automatic weapon selection equipment. The weapon selection equipment will choose between two types of systems—antimissile systems and retaliatory systems. It should be noted that several types of antimissile and retaliatory systems will be geographically distributed for maximum operation capability.

Figure 8 pictures the defense system in operation. Communications from forward outposts indicate an attack and transmit information on types, numbers, and courses of attacking vehicles. Computation and weapon selection are performed in the monitoring control center. Weapon selection can determine which antimissile system should be used —antiaircraft missiles, antimissile missiles for intermediate and short-range missiles, AICBM's, or antisatellite missiles to destroy armed enemy satellites. Retaliatory action must also be initiated to destroy enemy launching sites to prevent further attacks.

For defense against an ICBM attack, then, three events must occur in a matter of minutes: (1) the attack must be detected at an early stage; (2) defensive action must destroy enemy vehicles before they reach their targets; and (3) retaliatory action must neutralize enemy bases to prevent further attacks.

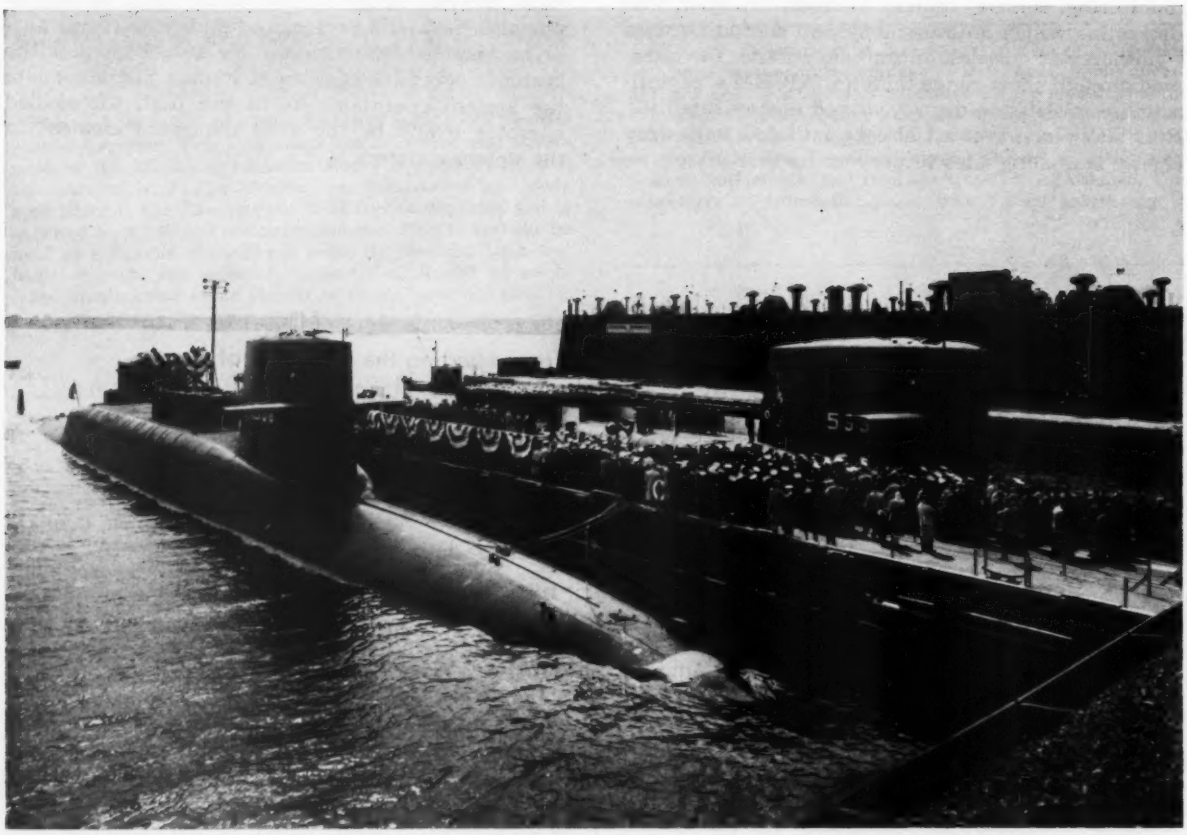
If we are to defend ourselves against an ICBM attack, we must employ a defense system similar to that described above. Such a system can be developed within our present philosophy of advanced weapon systems.

Although the system would be highly automatized, the role of the human being would be all important. He would perform a function that can never be assumed by machines. He would monitor the system's operation and inject human judgment into the system operation. As in the past, the skilled operator would be the most important element in the defense system.

The development of a new technique for evaluating the condition of aircraft engines, credited with the prevention of serious in-flight engine failures, was announced by the Navy. The process consists of analyzing samples of engine oil with a spectrometer to determine the identity and quantity of metals present. A one-ounce sample from the engine oil reservoir is burned between two carbon electrodes in a direct-reading spectrometer which identifies the metals and indicates their quantity. A high concentration of silver in the engine oil indicates a faulty bearing. A large amount of chromium denotes cylinder wall damage. Presence of large amounts of aluminum can indicate piston or valve guide failures.

The new technique was developed by the Bureau of Naval Weapons in its Engineering Materials Laboratory at the Naval Air Station in Pensacola. The Pensacola laboratory successfully adapted a technique which has long been used by railroads and other operators of diesel equipment for identifying and measuring the metal content of engine lubricating oils. It has not been applied previously to aircraft engines according to information available to the Bureau of Naval Weapons. The Bureau of Naval Weapons believes similar methods are theoretically applicable to gas turbine engines. The Naval Air Station, Pensacola engineers are presently engaged in testing this concept.

—from DEFENSE DEPARTMENT PRESS RELEASE



The nation's first two nuclear-powered Polaris-firing submarines shared the spotlight on April 9, 1960, as the Navy commissioned the second of them, the USS *Patrick Henry*, SSB(N)599, in ceremonies at General Dynamics Corporation's Electric Boat Division, Groton, Conn. Both the *Patrick Henry* and the USS *George Washington*, left, will become operational with their intermediate range Polaris missiles this year.

"JOURNAL OF THE INSTITUTE OF METALS"

THE SCIENTIFIC USES OF SPACE EXPLORATION

ACKNOWLEDGEMENT

This article is the reprint of a lecture delivered at the Royal Institution, London by Professor F. Hoyle, who is Professor of Astronomy and Experimental Philosophy at the University of Cambridge. It was published in the September 1959 issue of "Journal of the Institute of Metals."

I HAVE BEEN very impressed by a general hardening of the attitude of scientists who are not concerned with space research against such projects in general. This has occurred to such an extent that today it is not uncommon to hear certain of the space scientists, particularly those concerned with so-called space medicine, described as a "lunatic fringe."

Plainly, this is due, in part, to the grossly extravagant suggestions and plans that have been made. While it is true that far less extravagant claims are made by those responsible scientists who are advising Governments, it is unfortunately the case that exaggerated statements have indeed been put forward at an official level—a great many chickens are being counted before they are hatched.

In this lecture I want to review the possibilities as I see them. Perhaps I should begin by saying that I rate myself as being somewhere "in the middle of the road" so far as the controversy I have just mentioned is concerned. I shall put before you a few of the difficulties, and then (and this will occupy most of my lecture) I shall go on to describe the kind of work that might be done with extra-territorial devices. Later I may say a few words on why people want to explore space.

THE DIFFICULTIES OF SPACE EXPLORATION

Let me deal first with the difficulties involved. These are inherent and are of a kind that seem unlikely to be overcome by any remarkable new discovery. We hear talk of ion and photon rockets, but a trifling application of dynamics will show that much of this talk is nonsense. I will remind you of a few simple points. First, a rocket derives its forward motion from firing material in the opposite direction. It is true that the faster a given weight of material is fired out, the faster will be the forward motion of the rocket. Call this exhaust velocity V—then the larger V, the more efficient the rocket will be. For a given emission of material the thrust becomes greater and greater as the velocity goes higher. But unfortunately there is a relationship between the thrust and the heat produced inside the rocket, because with any system of propulsion which can be envisaged at present, heat must of necessity be produced inside the rocket. For 150 years and more people have been trying to produce a vehicle that could propel itself without heat being produced, but up till now no one has succeeded in any real sense. While it is true that an electric train achieves this end to a considerable extent, the amount of heat produced being comparatively

small, it must be remembered that the electricity used to drive the train is produced somewhere else —at the power station—where there is, of course, a great efflux of heat.

The relationship between thrust and heat may be expressed as: Thrust = Heat/V. It will be clear that there is a limit to the degree of heat that can be tolerated inside a rocket; otherwise the whole thing would go up in smoke. So that there is a maximum value permitted for the numerator of this formula. Suppose then we have a rocket designed to tolerate the maximum possible heat. All we can then do is to alter V, and the situation is that we can only increase the thrust by decreasing V, and this, of course, has the opposite effect on efficiency. If we want to get a really big thrust, we have to get it by comparatively small velocities of the kind produced in existing rockets. So I see no possibility of some marvelous discovery coming along to turn upside down our ideas concerning large thrusts.

Do we really need large thrusts? The answer is that we certainly do if a rocket is ever to get off the ground at all, because rockets are pulled back by the Earth. The requirement that the downward pull of the Earth's gravitational field must be more than balanced means then that the initial thrust has to be great. And having regard to the limitation I have just mentioned, this means that we must work with comparatively small exhaust speeds—not running to any very great number of kilometers per second. This is an inherent limitation and it is extremely difficult to see how any way can ever be found around it. If one were concerned only with pushing rockets about in free space, outside the Earth, where a big thrust is not needed, then of course this last consideration would become irrelevant. One might then visualize the production of rocket motors with extremely large exhaust speeds. One would have to work with small thrusts, but then this would not matter if there were no strong gravitational fields to overcome.

The effect of this limitation is to make the efficiency of the whole business of getting a pay load into space extremely poor. I will give a few figures. To get something into space the ratio of weight of rocket to pay load must be about 1000 to 1. If you want to get 1 ton into space, then you have to start with 1000 tons. This is a quite approximate figure. I will not quarrel with anybody who argues in favor of a ratio say of 400 to 1.

If we want to get the rocket only into satellite orbit and not out into space altogether, the situation is much better. Then the ratio is more of the order of 100 to 1. Here, then, there is the possibility that we might be able to get quite a number of tons into a satellite orbit starting with a rocket approaching 1000 tons in weight.

Now what is the situation if a human being is to go out into space *and to return*? The position is that if we require the human to be able to return under rocket power, i.e., to come back in the same way as he went out, the ratio becomes the square of the first figure; so that for the return trip the ratio is 1,000,000 to 1. If our space traveller and all his food and instruments weigh 1 ton—this is the effective pay load—he must still have 1000 tons of rocket fuel available on his return at the moment of plunging back into the Earth's atmosphere. So if he needs 1000 tons at this final stage, he must have 1,000,000 tons to start with.

The space travel people do not accept this calculation. They suggest that the returning traveller will have wings and will come in without requiring any substantial amount of power. But I think it is perfectly fair to say that this claim is completely without any scientific foundation. Such a returning traveller will approach the Earth at a speed of something over 20,000 mph. This may be compared with the maximum speeds at which conventional aircraft have flown—something in excess of 1000 mph. As you know, the Americans are arranging shortly to test a new device which is an intermediate stage between a rocket and a plane. According to reports, this device is expected to reach speeds of about 4000 mph. I would remind you that such a speed is still only one-fifth of the speed with which we shall eventually have to cope. And it is not really a matter of speed but of energy, which goes as the square of the speed. If, therefore, this new American plane works as well as its designers hope, it will still be coping only with about 4 per cent of the energy of a returning space traveller.

To add a final note of gloom on this matter, even if the returning space traveller had his 1000 tons coming into the Earth, it is much beyond present rocket techniques to be able to land smoothly on the surface of the Earth. The chances are heavily that he would go into the Earth with a bang, at a speed of about 1000 mph. Equally, existing techniques are fantastically below what will be needed to establish what is known as a "space platform." This is a device for accumulating materials slowly in a satellite going around the Earth, the materials being eventually used for a trip out from the Earth. As you will readily see, if you are to accumulate a space platform by firing up a whole lot of rockets, it will be necessary to have the skill and accuracy to be able to fire them all into almost exactly the same orbit. This is much beyond present-day techniques. It is comparable with, but more difficult than, arranging for two rifle bullets to meet in mid-air—the speed being about 20 times greater.

Before I finish this opening part of my talk, I might speak about whether I really believe that people will eventually go to the Moon. On the whole, I do. I believe that eventually somebody will do it, but I believe it will be done the hard way, by facing up to the ratios that I've just mentioned. I think eventually people will learn how to handle very big rockets of 10,000 tons or more.

HOW SPACE EXPLORATION COULD BE USED

But what can we reasonably envisage in the next decade, say up to the year 1970? As a guess let us say rockets up to 3000 tons. So if we look back at our ratios we see that if we start with 3000 tons we can put into satellite orbit a pay load of about 30 tons, or entirely out into space a pay load perhaps of 3 to 10 tons.

These are extremely useful weights enabling us to envisage the use of stabilized platforms. Instead of a rocket just carrying its instruments round and round, one could make steady observations.

With 30 tons available one could put quite a substantial telescope on a satellite. In quite a different category of space research from lunatic trips to the moon, we have to take quite seriously the possibility that a telescope and instruments of considerable weight, up to 10 tons or maybe more, can be put inside these vehicles, and that a stabilization technique can be mastered.

Assuming this is so, I would like now to describe some of the problems that we may hope to solve.

Figure 1 is a picture of the Moon. You will notice these pits, which are believed to be due to meteoric impact. We should like to get down into one of them. With 3 tons or more available, it might be possible actually to land equipment on the Moon itself. For example, we might land a television camera and thus transmit back to Earth a picture of the Moon. You will realize how much easier a project this would be than attempting to send a human being there. The sensible course will be to send television cameras and then merely sit by your fireside and look at the picture.

The dark areas which are to be seen on the Moon are something of a mystery. Scientists disagree as to what they are. Some believe they are flows of lava, while others imagine them to be huge deep drifts of dust. We should very much like to know for certain—not because this is an important scientific problem, but rather because it would be nice to know whether or not our processes of reasoning have been right. Often in astronomy we have to put our trust in reasoning processes, and if we were to find that our reasoning about this comparatively trivial problem were quite out of line, it would certainly decrease our confidence in making other statements about astronomy; vice versa, of course, if the situation were found to be such as we have deduced it to be, then our confidence would be increased.

Let me tell you of a more interesting problem that might be solved if rockets and their equipment were such that we could actually land equipment on the Moon. First, I must tell you something of the background of the problem. It is known that the temperature of the central regions of the Earth is about 5000°C. There are many lines of evidence to suggest that this is so. The question may be asked: why is the inside of the Earth hot? That question is answered quite satisfactorily by saying that when the Earth was formed it became compressed and the compression automatically heated the internal regions.

But in contrast to this, there is another very radical point of view that one might hold, namely, that radioactive materials—uranium in particular and to a lesser extent radioactive potassium—are not simply concentrated in the Earth's crust but exist throughout the whole mass of the Earth. If this were so, the amount of heat produced by radioactivity must have caused the interior regions of the Earth actually to boil on several occasions. It could indeed be said that many of the periods of great activity that have been inferred by geologists from their studies of the surface rocks in fact owed their origin to such outbursts. In other words, if there were such considerable amounts of uranium and potassium in the Earth, there would, in effect, be an "engine" capable of stirring up the Earth and causing great earthquake activity, creating mountain ranges, and so forth.

If this more radical point of view were correct, we should expect that the rocks inside the Moon would also contain radioactive materials, so that the interior of the Moon would be hot and fluid, as is the interior of the Earth. Under the first explanation, on the other hand, we should not expect the interior of the Moon to be hot, because the degree of compression there has been comparatively small. So we should like to know whether or not the inside of the Moon is fluid.

It may be asked: how may we find whether this is so? The procedure would be to land a seismograph at one part of the Moon and then cause a series of explosions at different parts of the Moon's surface. The vibrations resulting from the various explosions would travel through the Moon and would be received and recorded at the seismograph. We could thereby discover a great deal about the nature of the inside of the Moon and particularly whether or not the interior is liquid. That would be one rather useful problem we could solve.

I will now discuss some problems which I believe will probably be solved within the next four or five years. We should like to know, for instance, the density of the gas that exists between the planets. This is something inherently measurable by a rocket sent outside the Earth. Then, we want to know a great deal about the very high-speed particles which exist in regions outside the Earth—those that are "fired" from the sun and those that come to us from outer space. The separation of the two categories presents a very great problem. It is rendered particularly difficult for us down on the surface of the Earth because the Earth possesses a strong magnetic field which deflects the particles, so making it very difficult for us to determine the true situation as it must exist immediately outside the Earth. This,

Figure 1. Moon: last quarter showing N.E. quadrant.

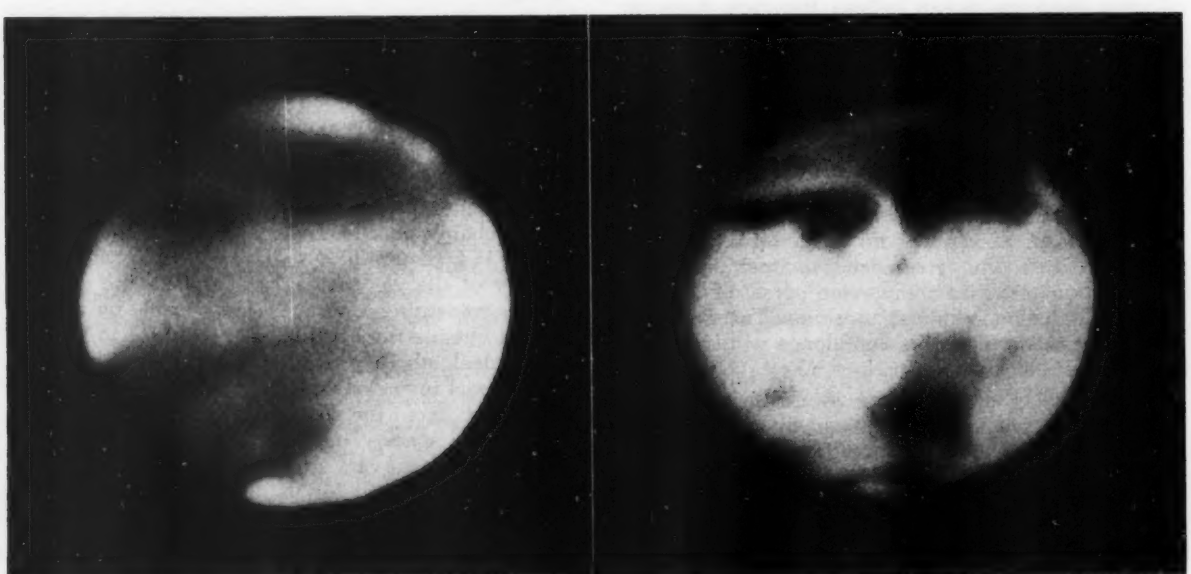
too, is something which no doubt will be cleared up within the next few years.

What of the other planets? Perhaps I ought to put it to you in this way: what we can see of the other planets, using a good telescope and under good conditions, is about equivalent to what we, on Earth, can see of the Moon with the naked eye. Even with the best instruments we can never hope to see more of the other planets than we can already see of the Moon; and it will be clear from Figure 1 how little detail we can see on the Moon with the naked eye. With some planets the position is indeed still worse for we cannot see anything at all, because they are always surrounded by clouds. All one can see in a telescope is a great cloudy mass. We have no hope of seeing through to the actual surface of the planet. I will now speak briefly about the different planets.

Figure 2 shows pictures of Mars taken under differing conditions. That on the left was taken under blue light, the other under red light. This is the kind of pattern one sees in a telescope. It is really quite poor. One would like to know something of the seasonal changes that are observed on Mars and whether the dark green patches which develop on its surface in the Martian spring are in some way related to plant life. This is a very worthwhile question to study—probably the most important thing we should like to know about Mars—because it would supply valuable information to the biologist. It would be particularly interesting to know whether life has developed on both the Earth and Mars, implying that the origin of life may not be at all an accidental process.

For the purpose of this study it would not be necessary for an actual landing to be made on Mars. In other cases, however, we may hope to use the method of landing suitable devices on satellites. Mars, for example, has two small satellites, and if it were possible to land suitable instruments on these, we should be able to get a really good close-up view and there would be no particularly difficult problems involved in getting out of the powerful gravitational pull of the planet.

Figure 3 is a picture of Venus. This is one of the cloudy planets and there is very little of it to be



(a) (b)

Figure 2. Mars, in blue (a) and red (b) light.

Figure 3. Venus, in blue light.

seen. It would be very useful to be able to break through to its surface and to transmit a television picture back to Earth.

Four pictures of Jupiter are shown in Figure 4. Here again we have a cloud-bound planet. Almost certainly it would be very wise in this case not to attempt to land on the planet because it is so enormous. It would be preferable to land on one of the satellites of Jupiter. There are many interesting problems connected with Jupiter which we should like to be able to answer. The very deep atmosphere around it can be clearly seen in the picture. It is an atmosphere which has considerable meteorology of its own. Very remarkable changes are going on, changes that it is a little difficult to imagine are caused by the Sun.

Figure 5 shows a picture of Saturn. Exactly the same applies there, and this should not escape consideration in any program for sending out space vehicles.

It is true that no one will be able to land any devices on the Sun, but a rocket fired dead at the Sun could survive until it got quite close. With such a rocket we could then proceed to learn a great deal from instruments. Surprisingly enough, it is tech-

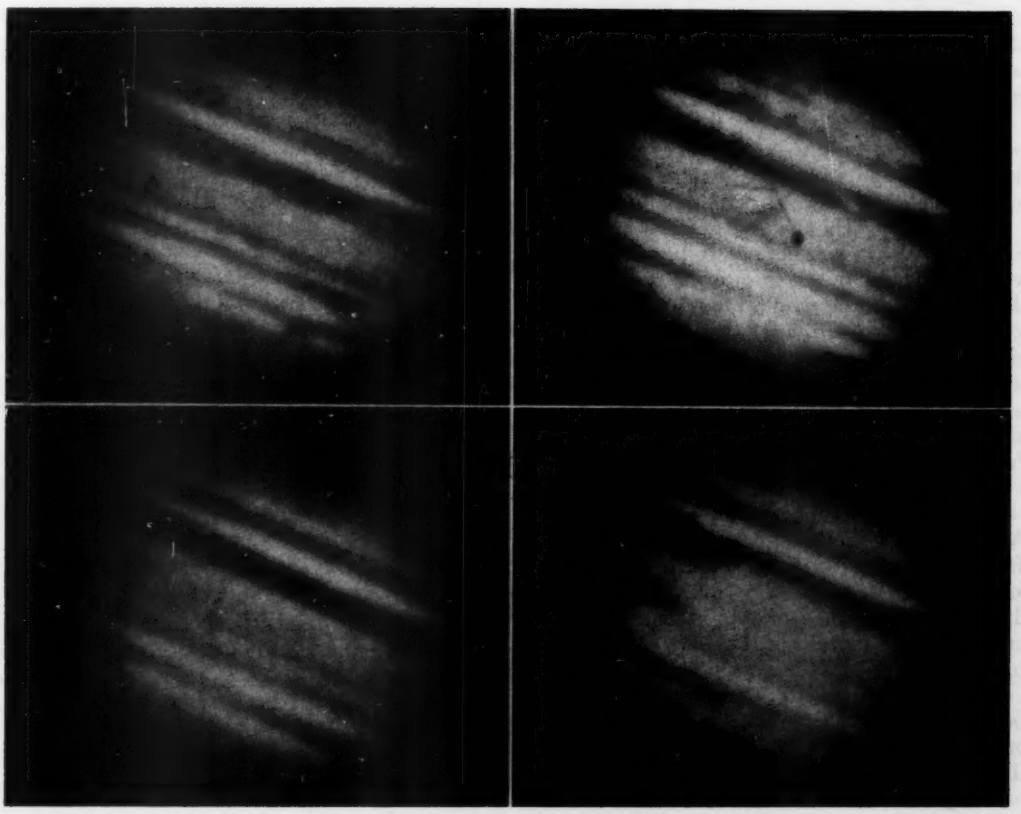


Figure 4. Jupiter, four photos: (A) shadows of satellite on disc; (B) satellite and shadow; exposures (A) and (B) separated by approx. 50 min.

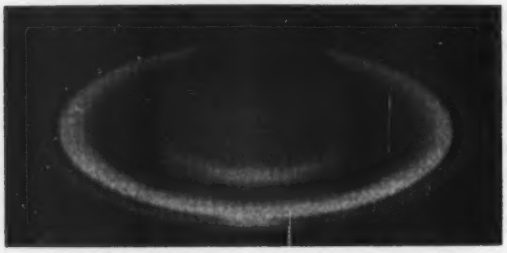


Figure 5. Saturn and ring system.

nically an extremely difficult task to fire a rocket dead at the Sun.

WIDER IMPLICATIONS OF SPACE EXPLORATION

I have given you a small selection of the kind of problems in which we might be interested I would like to come now to the broad principles of the whole question of space research. Here, down on Earth, we can see only a trifling proportion of the radiations that reach the Earth from outer space. If you will think of radiation as having pitches like notes on a piano, then there are in radiation not seven or eight octaves, but about 50; and with our eyes and photographic plates in cameras we can examine only a single octave out of those 50. A very large fraction of what we know about the Universe is based on this one window.

Do not misunderstand me here. It happens to be a particularly important window, enabling us to look at the stars. It is a window that is really determined by the Sun because our eyes are designed to work with the radiations that we receive from the Sun. As the other stars are in many respects similar to the Sun, it happens that we can study the stars in general, for we happen to have the right window for doing so; but it is quite certain that if we could look out on the whole range of radiations, our views about the Universe would be greatly changed.

As an example, in the last fifteen years people have begun to look at the Universe through a second window, namely, with the radio waves that also come through the atmosphere. You will have heard of the development of radio-astronomy. Radio waves are, of course, radiation of extremely low pitch. As a result of this new development we now know facts about the Universe which were quite unsuspected, and would never even have been guessed at but for the use of this second window. It is almost certain, therefore, that if we could use the whole spectrum, new and very startling information would come to hand. This is exactly what could be done if it were possible to mount a telescope on a satellite.

I will give you an example of some of the problems that might well be solved as a result of this. I have said that we happen to be favorably disposed for observing the stars. Although this is true for the majority of stars, there are nevertheless certain stars that we cannot see at all because they are much too blue. Their light is within the violet range, and some even in the X-ray region. We have every reason to believe that there will be X-ray stars, but there is no possibility of observing these from our position here on Earth. At the opposite extreme there are stars so red that their radiation falls into the infra-red range, and we do not see those either.

Perhaps even more important is the fact that stars are born inside very opaque clouds comprising masses of gas containing fine dust particles, which prevent us seeing through to the interior of the clouds. Thus we are in the exasperating position that we can never hope to observe the actual process of star formation. Although there is a great deal of evidence to show that stars are forming all the time, with present techniques we can observe them well only after they are born. The only means by which we could actually see through the clouds would be by the use of very red light. The dust would not then create such a serious difficulty. This possibility, again, would rest on our ability to make observations from outside the Earth's atmosphere.

There cannot be any question but that the use of instruments mounted outside the Earth's atmosphere is going to represent the beginning of an entirely new chapter in astronomy. I would guess that in the long run it is going to increase by a very considerable factor the scope and power of our methods of observation. If asked whether they would prefer either to put a telescope on a satellite or, alternatively, to have 10 per cent of the money to spend in other ways, probably 95 per cent of astronomers would make the latter choice. It is the case today that for the expenditure of comparatively trifling sums of money, astronomy could make enormous progress. For this reason, I believe most astronomers feel that when the case for space research is expressed in astronomical terms—in the terms that I have used in describing problems that we might hope to solve—the case is intellectually false. It is felt that if the community in general were really fired with the desire to solve problems in astronomy, there would be no lack of the comparatively small amount of money needed for current developments.

What, then, are the reasons for a program of space research? I would suggest that there are two reasons. The first, obviously, is defense, and about this I do not want to say very much. Compared with what will be needed to achieve some of these things of which I have spoken, the construction of an inter-continental rocket is quite an easy project. For this reason one might, perhaps, suppose that the defense motive will cease long before the development of a space research program achieves the technical efficiency needed for scientific research.

So perhaps we shall see constant development for these reasons.

The second reason is more healthy and praiseworthy. An enormous impetus to the development of instruments and instrumental techniques would be given by these programs. I suppose that in ordinary life, there is no great impetus to produce any complicated instruments much smaller than the wrist-watch. For social purposes we want wrist-watches, and so they are made, but there is, as yet, no demand for a piece of equipment of comparable complexity, and say one-hundredth the size of a wrist-watch; whereas this demand will arise more and more as we need to put more and more equipment into rockets.

Finally, there is the point that I made at an earlier stage, that rockets will have to get bigger and bigger, and of even greater weight, if we are to carry through the kind of space programs that are being mentioned. Perhaps when I spoke of a rocket weighing 10,000 tons you thought this was of enormous size; but I have a suspicion that in a future age a rocket of such weight will be considered quite ordinary, and that we shall reach a stage where we use really vast machines. It is very noticeable that machines built by man reflect the size of man himself. Our own height—say between 5 and 6 feet—is a dominating factor in the scale of the machines that we build. I know that there are such things as cranes which are specially built to deal with shipping and so on, but I foresee that in the future, there will be a whole range of machines and instruments, many of them much larger than ourselves, many smaller. The problems of space research are throwing these requirements into sharp relief.

In the civilian field there is likely to be very considerable industrial development in the future: in fact, most scientists feel that industry, far from having reached completion, has really only taken the "first bite at the cherry." Future developments will go ahead in response to the impetus to do certain things for which in the past no impetus has existed. I would suggest, therefore, that a space program supplies just such an impetus, and that this is important, quite apart from the scientific aspects of the program. Perhaps, indeed, a thousand years from now a whole range of new industrial developments will be seen to have sprung from this field of research.

ACKNOWLEDGMENT

Figures 1 to 5 are reproduced by courtesy of Mount Wilson and Palomar Observatories.

THE EARTH is solid down to its core, some 1,800 miles below the surface, and consists of a material about as strong as brick, higher structural strength than previously believed. There are no convection currents slowly churning over large masses of rock as some scientists believe, Dr. John A. O'Keefe of the National Aeronautics and Space Administration reported. He said his conclusion that the earth's mantle had great strength is based on the NASA discovery earlier this year of the earth's slightly pear-like shape and a recent new determination by the Army Map Service of how much the earth is flattened at the poles.

He reported that the flattening of the earth at the poles amounted to one part in 298.24 instead of the previously accepted international value of one part in 297.3. This seemingly small change confirms that the earth's structural strength is much greater than once thought. Mechanical strength equivalent to building brick is required to support the pear-like shape, Dr. O'Keefe said.

Studies of the orbital flight of Vanguard I, showed that the earth's sea level is 50 feet higher in the north polar region than previously thought and 50 feet lower in the south polar region. Accenting the pear shape is the fact that outside the polar areas, sea levels in the Northern Hemisphere are 25 feet lower than thought, and 25 feet higher in the southern Hemisphere.

—from SCIENCE NEWS LETTER
December 26, 1959

A ship's propeller running in open water, away from submerged bodies, has a perfectly smooth thrust and torque. However, any actual propeller is mounted sufficiently close to the hull or its appendages so that the velocity distribution is not uniform over the disc. Thus each individual blade will experience time-varying hydrodynamic forces with the result that vibration exciting forces in both thrust and torque are produced, with strong components of blade rate frequency and weaker components of multiples of that frequency. The torque excitation will produce torsional vibration in the shaft system, and the thrust excitation will produce longitudinal excitation. A conventional ship's shaft system is relatively "soft" in the torsional mode, but very stiff in the longitudinal mode. Only very large ships having long shafting and relatively high propeller speeds have a natural longitudinal frequency in the neighborhood of the exciting frequency. It can be shown that the ratio of the longitudinal frequency to the torsional frequency is approximately one and one-half times the ratio of the gyradius of the propeller to that of the shaft. Since this latter ratio is roughly ten to one in conventional design, the longitudinal natural frequency is about fifteen times that of the torsional critical. Thus both types of resonance would never give trouble on the same ship.

In new design, the condition is affected by the choice of the number of propeller blades, their tip clearance, and a judicious location of the thrust bearing along the shaft. Proper selection of these variables will fix a critical speed outside the critical excitation range. In existing design, longitudinal trouble can be easily attacked only by shifting the propeller to change the number of blades. It is apparent that for an infinite number of blades, no excitation would take place. It has been only in the past fifteen years that the five-bladed propeller has been adopted to decrease the difficulty. Previously, it had been thought that propeller efficiency would unduly suffer with the use of more than four blades. However, the success with the use of five-bladed propellers suggests the possibility of even more improvement with seven bladed propellers, if one could be designed with acceptable efficiency.

—from "VIBRATION;
A Survey of Industrial Applications"
by J. P. den Hartog

LIEUTENANT ALBERT G. STIRLING, U.S.C.G.

ZIRCONIUM, BERYLLIUM AND NIOBIUM IN NUCLEAR REACTORS

THE AUTHOR

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THE ADVENT of nuclear power has brought about an unprecedented demand for materials which have great heat and corrosion resistance and yet do not possess large neutron absorption coefficients. It is relatively easy to develop materials with the first two properties, but the requirement of a low absorption cross section is the real hooker in the problem. As an example, the Candu reactor has three-hundred and eight fuel positions which consist of 8.255 cm. inside diameter tubes of 0.414 cm. thick zircaloy-2. These tubes are subject to 1500 psi. coolant pressure, which induces a hoop stress of approximately 15,000 psi. With the addition of the thermal stresses, the total resultant stress is of the order of 17,000 psi. Since the generally accepted values of ultimate strength for this metal are in the neighborhood of 40-50,000 psi., it is easily seen how critical the design must be. Increasing the thickness by only twenty-five per cent, to bring the stresses more into line with present practice, would make the reactor economically unfeasible due to increased fuel costs to make up for the increased absorption of neutrons. This paper will present a summary of three of the new metals which are gaining acceptance or consideration in reactor design and construction.

ZIRCONIUM

Probably the most popular and presently one of the most used metals in reactor construction, other than the fuel materials, is zirconium. Zirconium was first discovered in 1789 by Klaproth, but it received little attention until 1948 when it was found that its cross section for neutron absorption was only 0.18 barns. Prior to this time, it was thought that the cross section was much larger, but this was found to be due to a hafnium impurity. In 1948, production in this country was less than ten pounds per year. Now production runs near ten million pounds per year.

Zirconium is a member of the second transition series of chemical elements and has two 4d electrons in an incomplete electronic shell. It is a metallic element with two solid state phases. Alpha zircon-

ium exists up to 865° C. The beta phase is stable from 865° C. to the melting temperature of 1845° C. The boiling point has been estimated to be 3700° C. Alpha zirconium is hexagonally close packed while the beta phase is a body-centered cubic. Randomly oriented, polycrystalline zirconium has a thermal expansion coefficient of 5.89×10^{-6} per degree centigrade. The density is 6.5 grams per cubic centimeter. When cold worked, it has the $[10\bar{1}0]$ direction as the preferred orientation. Its most common form is the alloy zircaloy-2 which is by weight per cent 1.5 Sn, 0.12 Fe, 0.10 Cr, and 0.05 Ni.

Zirconium ore is of two types, decomposed pegmatites found in Brazil and Madagascar, and beach sands found in Florida, Ceylon, Africa, Brazil, India and various places throughout Australia. It is the tenth most abundant element, being more plentiful than such common metals as zinc, lead, and copper.

Zirconium, in pig form, is either crystal bar zirconium or sponge zirconium depending on whether it is produced by the iodide decomposition process or the Kroll process, respectively. The sponge product is the more common and is the one which made zirconium economically feasible. Hafnium, because of its high absorption cross section, is the most undesirable impurity and generally is present in amounts varying between 0.05 and 2.0 per cent. However, the hafnium can be removed and in commercial grades is generally restricted to less than one hundred parts per million.

Zirconium has reasonable fabrication properties. It is a very active metal and when heated or melted must be protected by an inert gas blanket or a vacuum. Generally heating is done electrically by induction or carbon arc. When hot worked in contact with the atmosphere, an oxygen and nitrogen induced scale forms on the surface and must be removed. It may be hot worked by rolling or forging. The strength falls off rapidly with increasing temperature. The utlimate strength at 500° C is only 8,000 psi.

As previously mentioned, cold working of zirconium causes a preferred orientation. Twenty to thirty per cent cold work will increase its Rockwell B hardness from 20 to nearly 80 with a corresponding decrease in ductility. Its stress strain relationships are similar to other non-ferrous metals. Low neutron absorption and low strength at high temperatures have made possible the use of extruded zirconium clad fuel elements. There are some difficulties with the extrusion process, the most important is lubrication since the zirconium tends to gall if it touches the die wall. In general, the oxide coating which zirconium forms when in contact with air plus an oil and graphite mixture is a sufficient lubricant. Rotary swaging is also feasible with a reduction in section of fifty per cent before an anneal is necessary.

Zirconium is readily welded by the electric arc process under an inert gas blanket. Zircaloy-2 welds show some tendency to crack, especially when made under an argon blanket. This is believed to be caused by volatile impurities in the zirconium. Solid phase welding and diffusion welding are also feasible to bond zirconium to itself or to high zirconium alloys.

Pure zirconium has excellent corrosion resistant properties at elevated temperatures in an aqueous solution. During the initial period, the rate of corrosion actually decreases and then when the break-away point is reached the corrosion rate remains constant. The break-away point is so called because the corrosion product which has formed and has been protecting the surface by being very adherent now begins to flake off and to allow the rate of corrosion to increase.

It is easily seen why, with improved production methods and consequent reduction in price from five hundred dollars per pound in 1947 to four dollars and fifty cents per pound in 1958, zirconium has become the cladding and structural material used in nuclear reactors.

BERYLLIUM

One metal with tremendous potential in the nuclear field is beryllium. Beryllium's cross section for neutron absorption of 0.009 barns is two hundred times smaller than that of zirconium, and yet beryllium has approximately the same mechanical strength. Beryllium has the added advantage that it is a very efficient moderator (i.e. it has a large scattering cross section). Whereas zirconium has a detrimental effect on the reactor, beryllium when used as the structural and cladding material also acts as a moderator.

The main source of beryllium is the mineral ore, Beryl, which is a crystalline form of beryllium aluminum silicate. It is found in sizable deposits in Africa, Madagascar, and South Dakota. The ore is very difficult to concentrate in the normal manner since its density is so close to that of quartz, and therefore is generally concentrated by hand sorting of the ore. The later stages of concentration are done by one of the three chemical processes. In the United States the final purification is a magnesium reduction process of BeF which results in a product some ninety-seven per cent pure.

The chief problem with beryllium is its brittleness. It must be vacuum cast and considerable care must be used to prevent cracking upon cooling. To avoid these problems, considerable research is being carried out in the field of powder metallurgy.

Beryllium is a hexagonal close packed crystal, generally of quite large grain size. A method for grain refinement would be a major break-through for this material. It has an unusually low lattice c/a ratio that decreases with temperature. Beryllium is single phase up to 1262° C where a phase change is thought to take place. But this is so close to the melting temperature of 1315° C that it has

not been closely studied. The density is approximately 1.85 grams per cubic centimeter.

At present hot working of beryllium, especially extrusion, is receiving a great deal of effort. For extrusion, the beryllium is generally steel jacketed, and a reduction of area of twenty-five requires a pressure of fifty-five tons per square inch at 1000° C. A mixture of oil and graphite is used as a lubricant.

Beryllium is only slightly effected by radiation as demonstrated by its continued use in the Materials Testing Reactor as the moderator. The radiation effects shown are a slightly increased hardness and a reduced thermal conductivity. Some recent tests at Nuclear Metals Inc. have shown that beryllium is perhaps the best material for thermal shock resistance. Its resistance to thermal shock is least at 1050° C and, at this temperature, its resistance is twice that of aluminum.

One other handicap in the production of beryllium is the health hazard. Beryllium is very toxic and when inhaled in the form of mist, dust, or fumes, it causes a delayed type of pneumonitis. Proper ventilation is an absolute necessity in manufacturing and processing plants.

NIOBIUM

A third metal which is receiving considerable attention for possible uses in nuclear reactors is columbium or more correctly niobium. Niobium is a body-centered cubic element of group Va in the periodic table. It has a density of 8.57 grams per cubic centimeter and a thermal neutron absorption cross section of 1.1 barns which is four times that of zirconium. Its greatest advantage is its mechanical properties at high temperatures. Niobium is single phase up to the melting temperature of 2415° C and it retains its mechanical properties to 2200° F, being equivalent to pure molybdenum at this temperature. Annealed, it has a tensile strength of 44 to 50,000 psi and can be cold worked to a tensile strength of 100,000 psi. The Young's modulus is 10.4×10^{12} and the thermal coefficient of expansion is 7.1×10^{-6}.

Niobium's potential for nuclear reactors is as a structural element, a fuel cladding, and as an alloying element with the fuel. Though the other metals, such as beryllium and zirconium, which are used for these purposes have low cross sections and good corrosion resistance, they have very definite temperature limitations. While niobium does not possess as low a cross section, it far exceeds the other materials with respect to strength at high temperatures. In as much as the trend in nuclear reactors is to higher temperatures and pressures to improve thermal efficiency, niobium is certain to be of more and more usage in future reactors.

By the addition of ten atom per cent niobium to uranium, the body-centered cubic gamma phase of uranium is stabilized at room temperature. Normally this gamma phase occurs only at temperatures above 776° C. This stability gives uranium better corrosion resistance and better metallurgical properties than the alpha phase which is normally present at temperatures below 660° C.

In fast reactors the advantages of niobium are more pronounced as the thermal cross section is of less importance. However, due to this decrease in cross section importance, in fast reactors, niobium should be compared with stainless steels and vanadium.

Niobium was discovered in 1801 by Hatchett who noticed a strange constituent in some Connecticut ores he was processing. The ores of niobium are mined primarily in Africa with a few deposits throughout Europe, Asia, and the United States. This would break down, percentage wise, as follows: Africa 75 per cent; Europe and Asia 24 per cent, and the United States 1 per cent. The United States uses about ninety per cent of the total world production. Niobium is not overly abundant and the annual production is only about ten million pounds. A considerable amount of the ores, especially those found in the United States cannot be economically processed to obtain the niobium in any concentration or purity. They could be used however in case of a national emergency. The present price ranges from sixty to one hundred dollars per pound depending on its purity and form. It is available in sheet or powder form of purity up to 99.8 per cent.

It is easily cold worked and may suffer as much as a ninety-nine per cent reduction in area without an intermediate anneal. These cold working properties are indeed fortuitous since it is a very active metal at high temperatures. Indeed, its prime disadvantage is that at the very time its mechanical properties appear to best advantage its resistance to oxidation is least. As most other metals, niobium must, at high temperatures, be protected from air and the products of combustion by a cladding or some other protective coating. Thus, when it is used as a fuel cladding, it must either be clad itself or be in a reactor with some inert coolant such as the helium gas cooled reactor. Its mechanical properties are sensitive to gaseous impurities and therefore rather than melt and cast intricate shapes, powder metallurgy is used. For less complex shapes such as cladding and tubing, extrusion methods have proven to be very satisfactory. A review of the literature shows that either the reactions of niobium to aqueous solutions are not known or, that they remain a mysterious secret of the AEC. The latter seems more probable since niobium has received so much publicity for use in nuclear reactors.

SUMMARY

Thus, it is seen that the advent of nuclear power has, like all revolutions, brought with it many problems to be solved which require new materials and

techniques, The above three metals have been, or are being tested, to solve the problems that more common metals are not capable of solving. No one of these metals is an end-all for any particular problem and indeed each metal is beset with its own additional problems. That is, zirconium has good nuclear properties but poor mechanical properties at high temperature; beryllium has excellent nuclear properties, but is brittle; and niobium has fair nuclear properties and excellent high temperature mechanical properties but poor oxidation resistance. Therefore, it is evident that considerable research and development is required to perfect these metals or to replace them by some as yet untried element.

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A process for welding heavy sections by utilizing the current carrying capacity of the slag, or melt, to produce the heat is described in a recent article entitled "ELECTROSLAG WELDING" by R. D. Thomas. This is a process of electric welding wherein the heat necessary for fusing the filler metal and both sides of the joint is developed in the slag which covers the molten metal. The slag offers a resistance to the flow of electric current, and the heat thereby generated creates a melt having a temperature great enough to cause fusion of the metal. If in a submerged arc process, it were possible to arrange a dam to permit the accumulation of molten slag to form a one to one and one-half inch depth, the arc would disappear, the voltage would rise to 45 to 55 volts, and the current would be carried by the slag. This is the basis for the method.

The process is applicable primarily for plates at least 1 1/2 inches in thickness and can be used effectively for plates up to 10 inches thick. The speed of welding is 150 to 300 per cent faster than that of the submerged arc process, and a high deposition rate is obtained. The butt welding of long seams in heavy plates is the simplest use of the electroslag process. It lends itself well to the construction of heavy-walled cylindrical vessels. Although girth seams of these vessels present somewhat more of a problem, successful techniques are in use in European "Iron-Curtain" countries. The first industrial machine of this type to be set up in this country has been operating since about the middle of August 1959. The evaluation of welds made with different filler metals and fluxes is going forward in this installation, and other laboratory work is being done on the process.

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TETSUO NISHIYAMA

LIFTING-LINE THEORY OF THE SUBMERGED HYDROFOIL OF FINITE SPAN

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PART IV

Wall effect on the characteristics of the submerged hydrofoil of finite span.

(Editor's Note: This is the final part of this four part article.)

SYMBOLS

$2B$ = breadth of the tank
$2b$ = span of the hydrofoil
l = chord length of the hydrofoil
λ = aspect ratio
f = vertical distance from the still water level to the quarter chord point of the hydrofoil
C = advancing speed
$L(C_a)$ = lift (lift coefficient)
D = resistance
w = induced velocity
Γ = circulation
m = decrement coefficient of the lift curve slope due to fluid viscosity

The prime symbol denotes the corresponding value considering the effect of the tank wall side and the free water surface. The unprimed symbol is that in an infinite fluid.

INTRODUCTION

THE DIMENSIONS of an experimental tank, from the beginning, have been selected correspondingly to the size of model to be used. Under these circumstances, what are the effects the tank wall side on the characteristics of the submerged hydrofoil, the span of which is comparatively large in contrast with the breadth of a model? This problem, in spite of its importance in treating the experimental data, has not ever been considered thoroughly, insofar as the author is aware.

In this paper, adopting almost the same procedure as the theoretical treatments [3, 4, 5] for the wall effect of a wind tunnel, from the standpoint of the lifting-line theory, the allowable maximum span of the hydrofoil is examined for avoiding the tank wall effect and at the same time a correcting method is proposed for the effect of the tank wall side.

INDUCED VELOCITY

Now we take the origin 0 on the still water level and also on the center line of the experimental tank, with **ox**-axis in the direction of advance, **oy**-axis in the direction of span, and **oz**-axis vertically upward. The fluid motion in the tank due to the hydrofoil is hydrodynamically equivalent to that of an infinite number of hydrofoils which are the image series for the left and right wall side.

Therefore the velocity potential for the steady motion, satisfying the boundary condition of the free water surface, is given by [1]

$$\phi=R_e\Big|-\frac{i}{8\pi^2}\sum_{-\infty}^{\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec\theta d\theta\int_0^{\infty}e^{-K(Z+f)+iK\omega}dK$$

$$-\frac{1}{4\pi}\sum_{-\infty}^{\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_0^{\infty}e^{-u(Z+f)}\cos u\{y-2nB-(-1)^n\eta\}du$$

$$+\frac{i}{8\pi^2}\sum_{-\infty}^{\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec\theta d\theta\int_0^{\infty}e^{-K(f-Z)+iK\omega}dK$$

$$-\frac{1}{4\pi}\sum_{-\infty}^{\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_0^{\infty}e^{-u(f-Z)}\cos u\{y-2nB-(-1)^n\eta\}du$$

$$+\frac{iK_0}{4\pi^2}\sum_{-\infty}^{\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec^3\theta d\theta\int_0^{\infty}\frac{e^{-K(f-Z)+iK\omega}}{K-K_0\sec^2\theta+i\mu\sec\theta}dK\quad\cdots\cdots(1)$$

where

$$\omega=x\cos\theta+\{y-2nB-(-1)^n\eta\}\sin\theta,\quad K_0=g/c^2$$

For the time being, it is important to obtain the vertical induced velocity just at the position of the lifting-line. Accordingly, differentiating (1) by z and transforming the fifth term by the contour integration, the induced velocity is given by

$$w=-\frac{1}{4\pi}\sum_{-\infty}^{\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_0^{\infty}u\cos u\{y-2nB-(-1)^n\eta\}du$$

$$+\frac{1}{4\pi}\sum_{-\infty}^{\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_0^{\infty}ue^{-2uf}\cos u\{y-2nB-(-1)^n\eta\}du$$

$$-\frac{K_0^2}{\pi}\sum_{-\infty}^{\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_0^{\pi/2}\sec^5\theta\,e^{-2K_0f\sec^2\theta}\cos\{K_0\sec^2\theta\,(y-2nB-(-1)^n\eta)\sin\theta\}d\theta\quad..(2)$$

Transforming (2) by the well-known formula,* we can reduce to

$$w=-\frac{1}{4\pi}\lim_{m\to\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_0^{\infty}u\left\{\frac{\cos u(y+\eta)\sin 4mBu+\cos u(y-\eta)\sin(2m+1)2Bu}{\sin 2Bu}\right\}du$$

$$+\frac{1}{4\pi}\lim_{m\to\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_0^{\infty}ue^{-2uf}\left\{\frac{\cos u(y+\eta)\sin 4mBu+\cos u(y-\eta)\sin(2m+1)2Bu}{\sin 2Bu}\right\}du$$

$$-\frac{K_0^2}{\pi}\lim_{m\to\infty}\int_{-b}^{b}\Gamma(\eta)d\eta\int_0^{\pi/2}\sec^5\theta\,e^{-2K_0f\sec^2\theta}$$

$$\times\left[\frac{\cos\{K_0\sec^2\theta\sin\theta(y+\eta)\}\sin\{4mBK_0\sec^2\theta\sin\theta\}+\cos\{K_0\sec^2\theta\sin\theta(y-\eta)\}\sin\{(2m+1)2BK_0\sec^2\theta\sin\theta\}}{\sin(2BK_0\sec^2\theta\sin\theta)}d\theta\right.$$

$$\cdots\cdots(2')$$

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* $\cos\alpha+\cos(\alpha+\beta)+\cos(\alpha+2\beta)+\ \ldots\ +\cos\{\alpha+(n-1)\beta\}=\dfrac{\cos(\alpha+\frac{n-1}{2}\beta)\sin\frac{n}{2}\beta}{\sin\frac{\beta}{2}}$

Assuming the distribution of the circulation to be elliptic, and applying the Dirichlet's integral theorem to the each term, we obtain after some reduction:

$$\Gamma(\eta)=\Gamma_0\sqrt{1-\eta^2}\ ;|\eta|\leqq 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$w=-\frac{\pi\Gamma_0}{4B}\sum_1^\infty J_1\left(\frac{\pi kb}{2B}\right)\cos\frac{\pi kb}{2B}y\ )$$

$$+\frac{\pi\Gamma_0}{4B}\sum_1^\infty e^{-\pi kf/B}J_1\left(\frac{\pi kb}{2B}\right)\cos\left(\frac{\pi kb}{2B}y\right)$$

$$-K_0b\frac{\pi\Gamma_0}{4B}\left\{e^{-2K_0f}+\sum_{k=1}^\infty\frac{4\sec^2\theta_k e^{-2K_0f\sec^2\theta_k}}{1+2\sin^2\theta_k}\cdot\frac{J_1\left(\frac{\pi kb}{2B}\right)}{\frac{\pi kb}{2B}}\cos\left(\frac{\pi kb}{2B}y\right)\right\}\ldots.(2'')$$

where θ_k are the roots of the equation

$$2BK_0\sec^2\theta_k\sin\theta_k=\pi k;\ k=0,\ 1,\ 2\ \ldots\quad\ldots\ldots.(4)$$

and J_1 is the Bessel function of the first kind. It can be easily shown that the vertical induced velocity is related only to the free vortex and regular free waves.

Now we put, for the convenience of calculation,

$$w'=w+\Delta w \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$w=-\frac{\Gamma_0}{4b} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$\Delta w=\frac{\Gamma_0}{4b}-\frac{\pi\Gamma_0}{4B}\sum_1^\infty J_1\left(\frac{\pi kb}{2B}\right)\cos\left(\frac{\pi kb}{2B}y\right)+\frac{\pi\Gamma_0}{4B}\sum_1^\infty e^{-k\pi f/B}J_1\left(\frac{\pi kb}{2B}\right)\cos\left(\frac{\pi kb}{2B}\right)y$$

$$-K_0b\frac{\pi\Gamma_0}{4B}\left\{e^{-2K_0f}+\sum_{k=1}^\infty\frac{4\sec^2\theta_k e^{-2K_0f\sec^2\theta_k}}{1+2\sin^2\theta_k}\frac{J_1\left(\frac{\pi kb}{2B}\right)}{\frac{\pi kb}{2B}}\cos\left(\frac{\pi kb}{2B}y\right)\right\}\quad\ldots\ldots.(7)$$

Then Δw shows the variation of the induced velocity by the effect of the free surface and tank wall side.

LIFT AND RESISTANCE IN THE SUBMERGED CONDITION WITH THE EFFECT OF THE TANK WALL SIDE

The lift and resistance changes correspondingly to the variation of the induced velocity. At first, the change of the lift can be obtained by regarding the angle of attack as increasing by $\Delta w/c$; namely, the circulation can be given by

$$\Gamma'=\Gamma+\frac{d\Gamma}{d\alpha}\cdot\frac{|\Delta w|}{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

On the other hand the relation holds from the Kutta-Joukowsky's theorem

$$\Gamma=\frac{1}{2}cc_al \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Further we have a relation between Γ_0 and c_a for the elliptic distribution of the circulation.

$$\Gamma_0=\frac{1}{1+\frac{i}{4\lambda}}\cdot\frac{1}{2}clc_a \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

where

$$i=\frac{dc_a}{d\alpha}$$

Then we obtain from (9) and (10)

$$\frac{d\Gamma_0}{d\alpha}=\frac{clm\pi}{1+\frac{m\pi}{2\lambda}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Accordingly the circulation can be given from (8) and (11)

$$\Gamma'=\Gamma+\Delta\Gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots (8')$$

$$\Delta\Gamma=\frac{clm\pi}{1+\frac{m\pi}{2\lambda}}\sqrt{1-y^2}\left[\frac{\Gamma_0}{4cb}-\frac{\pi\Gamma_0}{4cB}\sum_1^\infty J_1\left(\frac{\pi kb}{2B}\right)\cos\left(\frac{\pi kb}{2B}y\right)+\frac{\pi\Gamma_0}{4cB}\sum_1^\infty e^{-k\pi f/B}J_1\left(\frac{\pi kb}{2B}\right)\cos\left(\frac{\pi kb}{2B}y\right)\right.$$

$$\left.-K_0b\frac{\pi\Gamma_0}{4cB}\left\{e^{-2K_0f}+\sum_{k=1}^\infty\frac{4\sec^2\theta_k e^{-2K_0f\sec^2\theta_k}}{1+2\sin^2\theta_k}\cdot\frac{J_1\left(\frac{\pi kb}{2B}\right)}{\frac{\pi kb}{2B}}\cos\left(\frac{\pi kb}{2B}y\right)\right\}\right]\ldots\ldots.(12)$$

The lift in the submerged condition or in an infinite fluid can be given respectively by:

$$L'=\rho c\int_{-b}^{b}\Gamma'(y)dy \quad \ldots\ldots\ldots\ldots\ldots\ldots (13) \qquad L=\rho cb\Gamma_0\frac{\pi}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

And then we obtain finally

$$\frac{L'}{L}=1+\frac{\frac{\pi m}{2\lambda}}{1+\frac{\pi m}{2\lambda}}\,I \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

where

$$I=1-2\pi q\sum_{1}^{\infty}\frac{J_1^2\left(\frac{\pi kq}{2}\right)}{\left(\frac{\pi kq}{2}\right)}+2\pi q\sum_{1}^{\infty}e^{-k\pi t/B}\frac{J_1^2\left(\frac{\pi kq}{2}\right)}{\left(\frac{\pi kq}{2}\right)} \quad -2\pi qK_0b\left\{\frac{1}{2}e^{-2K_0t}+4\sum_{k=1}^{\infty}\frac{\sec^2\theta_k\cdot e^{-2K_0t\sec^2\theta_k}}{1+2\sin^2\theta_k}\frac{J_1^2\left(\frac{\pi kq}{2}\right)}{\left(\frac{\pi kq}{2}\right)^2}\right. \quad \ldots (16)$$

and

$$q=b/B$$

Similarly, the resistance in the submerged condition or in an infinite fluid can be given respectively

$$D'=\rho\int_{-b}^{b}(\Gamma+\Delta\Gamma)(w+\Delta w)dy \quad \ldots\ldots\ldots (17) \qquad D=\frac{\pi}{8}\rho\Gamma_0^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

then we obtain finally

$$\frac{D'}{D}=1-\frac{I}{1+\frac{\pi m}{2\lambda}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (19)$$

LIFT AND RESISTANCE IN THE SUBMERGED CONDITION WITHOUT THE EFFECT OF THE TANK WALL SIDE

It is necessary to obtain the lift and resistance without the effect of the tank wall side by the same procedure and method as that with the effect of the tank wall side.

Similar to that with the effect of the tank wall side, the characteristics without the effect of the tank wall side are as follows:

Induced velocity:

$$w'=-\frac{\Gamma_0}{4b}+\Delta w \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

$$\Delta w=\frac{\Gamma_0}{4}\int_0^{\infty}e^{-2uf}\cos(buy)J_1(bu)du-K_0^2b\Gamma_0\int_0^{\pi/2}\sec^5\theta e^{-2K_0f\sec^2\theta}\cos(K_0b\,y\sec^2\theta\sin\theta)\frac{J_1(K_0b\sec^2\theta\sin\theta)}{K_0b\sec^2\theta\sin\theta}d\theta \quad \ldots (21)$$

Circulation:

$$\Gamma'=\Gamma+\Delta\Gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

$$\Delta\Gamma=\frac{1\pi m}{1+\frac{\pi m}{2\lambda}}\Delta w\sqrt{1-y^2} \quad \ldots\ldots\ldots\ldots\ldots (23)$$

Lift:

$$\left[\frac{L'}{L}\right]_{B=\infty}=1+\frac{\frac{\pi m}{2\lambda}}{1+\frac{\pi m}{2\lambda}}1 \quad \ldots\ldots\ldots\ldots\ldots (24)$$

Resistance:

$$\left[\frac{D'}{D}\right]_{B=\infty}=1-\frac{I}{1+\frac{\pi m}{2\lambda}} \quad \ldots\ldots\ldots\ldots\ldots (25)$$

where

$$I=2\int_0^{\infty}e^{-2uf}\frac{J_1^2(bu)}{u}du$$

$$-8K_0^2b^2\int_0^{\pi/2}\sec^5\theta\,e^{-2K_0f\sec^2\theta}\frac{J_1^2(K_0b\sec^2\theta\sin\theta)}{(K_0b\sec^2\theta\sin\theta)^2}d\theta \quad (26)$$

SPECIAL CASE

Now we consider an interesting special case. When we take the submersion depth adequately large, the effect of the free water surface naturally diminishes; hence Δw shows the variation of the induced velocity by the effect of the tank wall side only. This case corresponds to that in the wind tunnel, for which case Glauert's approximate solution [2] has been published.

$$\lim_{f\to\infty}\left[\frac{L'}{L}\right]=1+\frac{\frac{\pi m}{2\lambda}}{1+\frac{\pi m}{2\lambda}}\,I \qquad \text{.....(27)}$$

$$\lim_{f\to\infty}\left[\frac{D'}{D}\right]=1-\frac{I}{1+\frac{\pi m}{2\lambda}} \qquad \text{.....(28)}$$

where

$$I=1-2\pi q\sum_{1}^{\infty}\frac{J_1^2\left(\frac{\pi kq}{2}\right)}{\left(\frac{\pi kq}{2}\right)} \qquad \text{.....(29)}$$

NUMERICAL EXAMPLES

In order to check the data[6] in NACA Langley tank from the standpoint of the effect of the tank wall side, we take the test condition as a numerical example.

aspect ratio	$\lambda = 10$
submersion depth	$f = 0.841$
tank breadth	$b/B = 0, 0.5, 0.7$
span form	rectangular

LIFT AND RESISTANCE

Curves are shown for the variation of the lift and resistance with the Froude number in Figures 1 and 2; from these results we can easily see that the lift increases and the resistance decreases by the effect of the tank wall side. In other words the effect of the free water surface is canceled more or less, by the existence of the tank wall side.

Curves are shown for the variation of the lift and resistance with the breadth of the tank; taking into account that this numerical example almost corresponds to the normal condition of operation, we can safely conclude that the allowable span of the hydrofoil may be less than half the breadth of the tank in order to avoid the effect of the tank wall side. Namely we have

$$b/B \leqq 0.5$$

Accordingly, if we select the span of the hydrofoil from this result, the pure effect of the free water surface can be taken out.

Further, from Figures 3 and 4, we can also see that the measured data in NACA No. 1 and 2 tank do not contain the effect of the tank wall side.

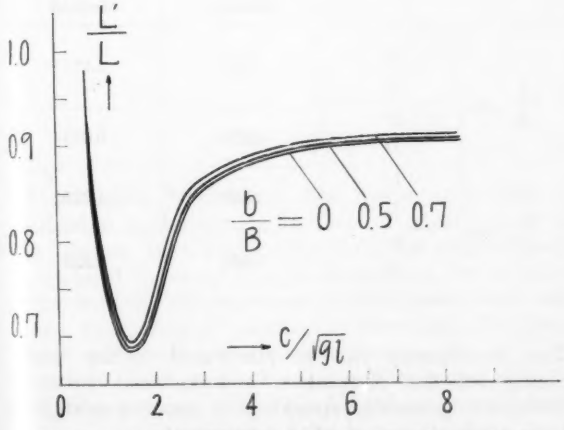

Figure 1. Variation of lift with the Froude number.

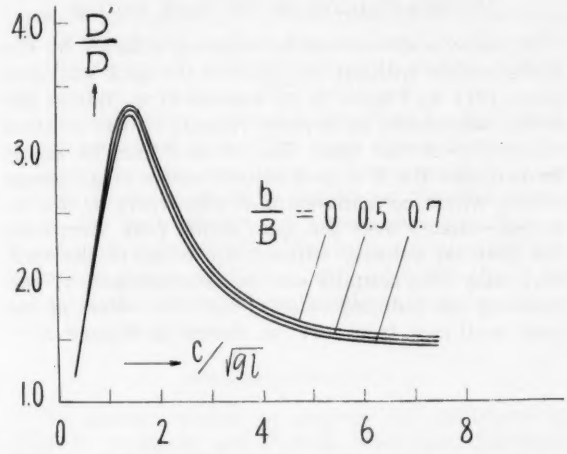

Figure 2. Variation of resistance with the Froude number.

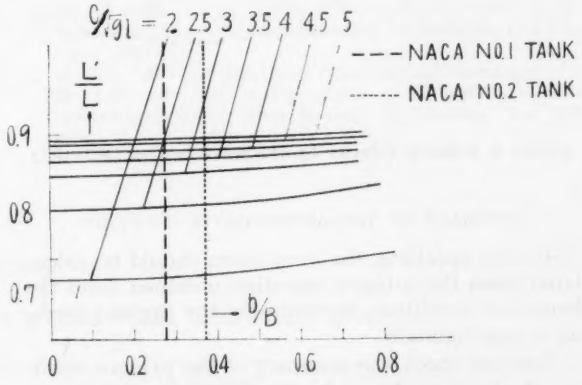

Figure 3. Variation of lift with the tank breadth.

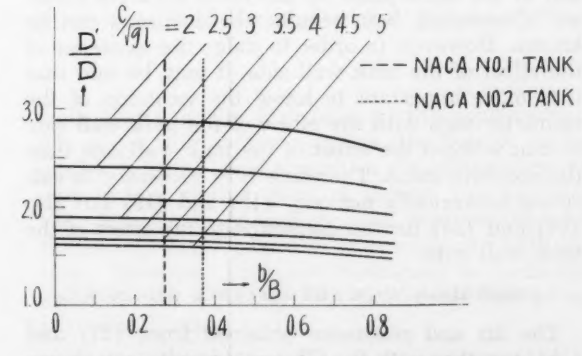

Figure 4. Variation of resistance with the tank breadth.

INDUCED VELOCITY BY THE WAVE MOTION

A curve is shown for the induced velocity by the wave motion without the effect of the tank wall side from (21) in Figure 5; its feature is to induce laterally sidewards, an inverse velocity to the induced velocity over the span. Therefore it can be easily known that the first and second image of all image series, which contributes most effectively to the induced velocity over the span in the tank, decreases the induced velocity without the effect of the tank wall side. This actually can be demonstrated by calculating the induced velocity with the effect of the tank wall side from (7), as shown in Figure 5.

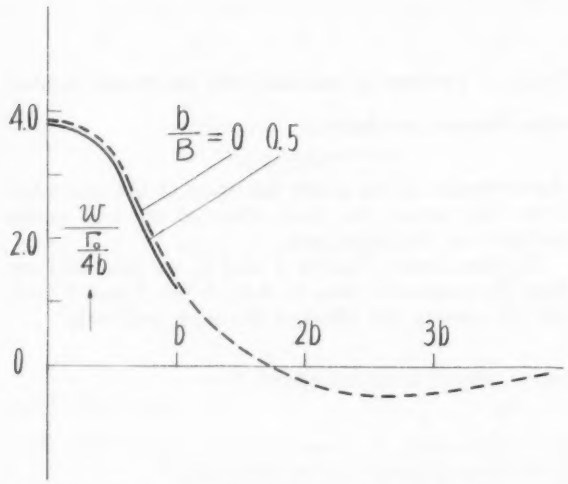

Figure 5. Induced velocity by the wave motion ($K_0 f$=0.1)

ACCURACY OF THE APPROXIMATE SOLUTION

Strictly speaking, the circulation should be calculated from the integral equation obtained from the boundary condition. Accordingly the present method is approximate.

Now we check the accuracy of the present method. Curves are shown for the lift and resistance in Figures 6 and 7 from (24) and (25), respectively, and at the same place by the more accurate method.[1] Comparing both results, the accuracy can be known. However, in order to judge the existence of the effect of the tank wall side, it may be said that it is more important to know the variation of the characteristics with the effect of the tank wall side to that without the effect of the tank wall side than the absolute value. Therefore it is necessary to calculate numerically not only (15) and (19) but also (24) and (25) for the correction to the effect of the tank wall side.

COMPARISON WITH THE GLAUERT'S SOLUTION [2]

The lift and resistance obtained from (27) and (28), together with the Glauert's results, are shown

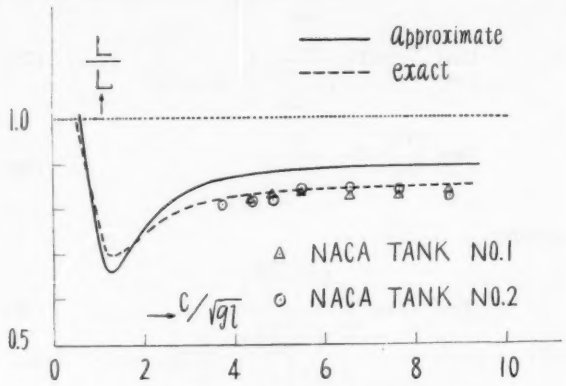

Figure 6. Comparison for Lift.

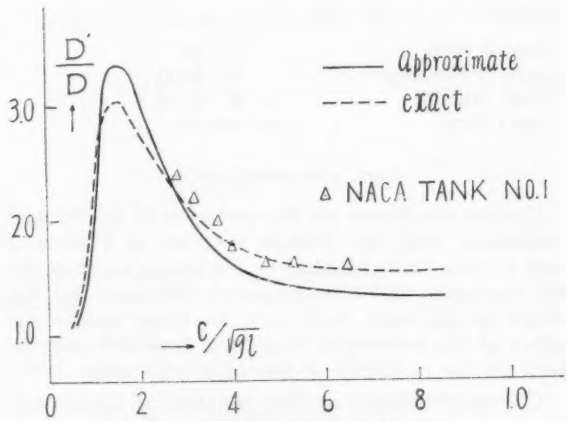

Figure 7. Comparison for resistance.

in the following table:

		Glauert	Present Method
$\frac{b}{B}$=0.5	$\frac{L'}{L}$	1.012	1.017
	$\frac{D'}{D}$	0.910	0.870
$\frac{b}{B}$=0.6	$\frac{L'}{L}$	1.016	1.022
	$\frac{D'}{D}$	0.862	0.820

The discrepancy can be attributed to the treatments for the circulation and induced velocity. However, generally speaking, it can be said that both methods are in good agreement.

CONCLUSIONS

Considering the effect of the tank wall side on the characteristics of the submerged hydrofoil of finite span from the lifting-line theory, the theoretical expressions are deduced and numerical calculations are made for the lift and resistance.

The main results obtained are as follows:

(1) Under the effect of the tank wall side the lift increases and the resistance decreases but its absolute value of variation is comparatively small.

(2) In order to avoid the effect of the tank wall side for the normal condition of operation, it is necessary to take the maximum allowable span less half the breadth of the tank.

SUMMARY

The analytical treatments reported in the JOURNAL are summarized briefly as follows:

(1) For the two dimensional problems

a. An exact method as well as an approximate method were proposed for obtaining the characteristics of the submerged hydrofoil of arbitrary sections (August 1958 JOURNAL).

b. A successive approximate method was proposed for obtaining the profile form of the submerged hydrofoil with a prescribed pressure distribution (November 1958 JOURNAL).

c. The characteristics of the submerged hydrofoil were examined among stationary waves (February 1959 JOURNAL).

(2) For the three dimensional problems

a. An analytical method was proposed for obtaining the characteristics of the submerged hydrofoil of finite span (August 1959 JOURNAL).

b. The effect of a dihedral angle on the characteristics was examined (November 1959 JOURNAL).

c. A designing method was proposed for the submerged hydrofoil with the optimum distribution of circulation (February 1960 JOURNAL).

d. A correcting method is proposed for the effect of the tank wall side (This issue of the JOURNAL).

Thus from the standpoint of wave-making, theoretical researches may be considered finished. However, the hydrodynamical phenomena peculiar to the submerged hydrofoil—for instance, air-drawing, hydraulic jump, cavitation, etc.—still remain to be solved in the future. These problems must be solved only by experiment.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Prof. F. Numachi and Prof. S. Fuchizawa for their inspiring discussions and cordial guidance throughout his study.

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DISCUSSION

"LIFTING LINE THEORY OF THE HYDROFOIL OF FINITE SPAN"

PART IV

by TETSUO NISHIYAMA

By Dr. B. Silverstein, Ship Design Division, Bureau of Ships

PROFESSOR NISHIYAMA has made a number of valuable contributions to the "classical" study of hydrofoils. In a frictionless fluid, he utilized techniques of potential flow to determine the pressure distribution, lift and drag of foils near a free surface, the "inverse" problem of deriving a foil shape from a desired pressure distribution, etc.

In this last paper, Professor Nishiyama aids the experimenter by deriving tunnel or model basin wall effects on the test data. At the conclusion of this paper, the author suggests that future studies are likely to be concentrated in experimental work, with only a limited effort in theory. I believe that this thought is pessimistic and that considerable theoretical development is in process and will continue. However, Professor Nishiyama is, unfortunately, correct when he implies a severe lack of experimental data.

In order to bring these ideas into perspective, I would like to present my opinions as to the future of hydrofoil craft. The past has been well documented. Alexander Graham Bell flew a boat on wings. Since then the record has been dotted with notable successes and failures. Each success brought an upsurge of enthusiasm, each failure tended to send the hydrofoil principle to obscurity. There has been, however, a continuing direction of development and boat-building, both in this country and in Europe. In the last four or five years, the effort in the United States has expanded considerably. Perhaps the greatest boon to the American hydrofoil program is the recent design of an operational naval craft, the PC(H). This boat, due to be completed sometime in 1962, will perform an anti-submarine warfare mission at speeds in excess of forty knots in rough seas. This serves notice that the U.S. Navy, necessarily conservative in the design of ships, has evidence to believe that hydrofoils are practical and can perform vital missions.

An equally important milestone in the history of hydrofoil development was the signing of a contract early in 1960 by the Maritime Administration with Grumman Aircraft Company for the building of an 80 ton, 60 knot hydrofoil boat. This boat will eventually be capable of operating on supercavitating foils at 80 knots.

There are clearly both military and commercial possibilities for hydrofoil craft. With the practicality established, it remains to determine suitable missions for hydrofoil craft. Anti-submarine warfare, ferries, amphibious vehicles, coast guard cutters, etc., immediately come to mind, the next, and an ever-present need is the establishment of design methods and criteria. In this area, considerable work has been done, and an enormous amount of experimental and theoretical study must yet be developed.

A hydrofoil design handbook was compiled in 1954 by Gibbs and Cox, Inc. This book digested and correlated much of the available data at that time and put it into a form usable in design. Since 1954, considerable effort has gone into previously undeveloped areas such as the characteristics of supercavitating foils and propellers, stability of hydrofoil systems, etc. This information is found scattered through the technical journals. It is in these newer areas, where the time is ripe for extensive theoretical and experimental efforts.

The modern concept of hydrofoil craft is that of a fast, all-weather boat. The speed aspects of design and performance have been paramount since the first concept of flying on wings in water. As an aside, it has been pointed out by all practical hydrofoil designers that the lift and drag characteristics cannot be simply lifted from NACA foil data. The parasite drags associated with struts, power pods, etc., reduce the lift-drag ratios for practical boats to about 10 to 15. This is an order of magnitude less than that claimed by some hasty inventors. Nevertheless, useful hydrofoil craft can be designed with a lift-drag ratio of 10.

It appears that a speed of about 60 knots represents the top speed of sub-cavitating foils. Above this speed, cavitation is extensive, with its concurrent erosion and short life for the foils. Our present need for high-speed surface ships indicates a substantial pay-off for craft in the 80-100 knot speed range. It is here that the super-cavitating (or ventilated) foils become extremely useful. Yet, what data is available for the designer? The Office of Naval Research has sponsored considerable research into the fundamental mechanism of supercavitation and ventilation; there still remains some rather important information:

1. What are the lift, lift-drag ratio vs. angle of attack of various planforms, section shapes and aspect ratios?
2. How are the characteristics of the above wings affected by struts and nacelles holding propellers?
3. How does one design and what are the force and moment characteristics of flapped supercavitating foils?
4. What are the air requirements for ventilated foils?

There are many more basic design problems, concerning speed of hydrofoils, that have yet to be resolved.

I would like to emphasize, however, the second aspect of our modern concept of hydrofoil craft—that is, the all-weather capacity. In the simplest form, we are concerned with the stability and control characteristics in calm water. A boat with submerged foils forward and aft, such as the PC(H), requires an automatic pilot for maintaining flight; boats with surface-piercing foils have inherent vertical stability (except in some following seas, which places a limitation on these craft). How do we design the foils, flaps and autopilot (if necessary) to give the desired flight characteristics? How do we design the rudders, especially since the onset of undesired aeration down the struts is not predictable by present-day knowledge? For sub-cavitating foils, theories and experimental data for stability have been developed. (The PC(H) was tested extensively.) We have practically no data on the flight stability of super-cavitating foil systems.

We have a serious shortage of information on stability and control in calm water and an even more severe lack in the area of predicting the behavior of hydrofoil craft in waves. These unsteady effects on the forces and moments of both sub- and super-cavitating foils must yet be determined. Fairly complete equations of motion have been worked out. The coefficients in these equations, for the most part, should be determined empirically. Due primarily to a lack of adequate facilities and

personnel, this important area has been relatively unexplored. An evaluation of the variation of these coefficients with systematic geometric changes would be extremely useful.

Many of the hydrofoil craft in existence today have demonstrated the possibility of small motions in a seaway. Today, however, we do not possess the knowledge to design the desired minimum motions into a new hydrofoil boat. It is in this area, the characteristics of a system of hydrofoils in a seaway, where much fruitful theory and experimental data can be developed.

Researchers, such as Professor Nishiyama, are finding that the problems in stability and motion of hydrofoil craft are diffiicult and challenging. The hydrofoil designer will never be sure of the performance, or even the survival, of a new craft until this area is adequately explored.

Marine salvage often poses some awkward problems, and sometimes offers substantial rewards for its successful conclusion. In a salvage job in Sweden, the work is on a Swedish warship which sank near Stockholm just 331 years ago, and has remained at a depth of 18 fathoms ever since.

Why the warship Vasa, a 44-gun three-decker ship of the line, and the pride of the Swedish fleet at the time, sank almost without warning on her maiden voyage, has never been satisfactorily explained. Perhaps the salvage, when completed, will throw some light on this problem. But even if it does not tell the reason for the disaster, it will provide a lot of information about the appearance and technical details of warships of the time. At present the oldest preserved ship in the world is Nelson's Victory, and she has by no means remained unaltered since she was built. Vasa, on the other hand was commissioned more than a century before Victory was launched, and she has lain until now in a bed of clay, covered with silt and mud, which have protected the hull; it is certain, too, that the ship's timbers will be free from worm, as the teredo worm is not found in the Baltic.

The salvage plan adopted was that of lifting the hull in stages by means of steel cables looped under it and made fast to two pontoons, one each side, which, as water ballast was pumped out, brought the hull up from the sea bed and enabled it to be towed for some distance before it bottomed again. To enable the cables to be drawn under the ship the divers cut six tunnels, each about 65 ft. long. As a result of 17 lifts by the pontoons, the Swedish Neptun Salvage Company, who are responsible for the salvage work, have moved the Visa to a point near the shore of Kastell Holmen, the naval depot at the entrance to the inner harbor of Stockholm. Here she lies in 8 fathoms of water, having suffered no damage on the way.

Operations have now been suspended for the winter. This spring, the divers will use high pressure air and water lines to clear the hull of the accumulated mud and silt of three centuries. This work is calculated to occupy the whole of the summer working season this year, and it will not be until 1961 that the final stage of salvage can take place.

—from ENGINEERING
November 20, 1959

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our rsponsibilities sober us; our adversities strengthen us.
Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

MOHR CIRCLE FOR OBLIQUE BENDING DEFLECTIONS

ACKNOWLEDGMENT

This article was written by T. F. W. Smith, Senior Lecturer at Brighton Technical College. It appeared in the November 27, 1959 issue of "The Engineer," and is reprinted therefrom.

THE MOHR CIRCLE is well known for its applications to stress, strain and second moments of area. A similar kind of circle may be derived for the deflections of a beam under oblique bending, providing not only a convenient graphical method of determining the deflections, but also a clear means of showing how the deflection varies with the rotation of the beam relative to the loading.

DERIVATION OF DEFLECTION CIRCLE

Suppose a uniform beam to be bent by a given loading system so that at every cross section the bending moment is exerted about principal axis VV, as shown for an unequal angle section in Figure 1 (a). Let the deflection caused at specified section be Δ_{P_1}. Now let the beam be rotated relative to the loading until the bending moment acts about principal axis UU, as in Figure (b), and let the deflection at the specified section now become Δ_{P_2}. Δ_{P_1} and Δ_{P_2} may be termed the "principal deflections" for the section concerned when the beam rotates relative to the given loading system. Both these deflections are in the same sense relative to the loading and both are in the load plane, being unaccompanied by any sideways deflection. Δ_{P_1} is greater than Δ_{P_2} since the principal second movement I_u is greater than I_v.

If the beam is inclined as in Figure 1 (c), having revolved anti-clockwise through angle θ from the original position when VV was perpendicular to the load plane, then the deflection at the specified section consists of a component $\Delta_{P_1} \cos\theta$ along UU and a component $\Delta_{P_2} \sin\theta$ along VV. The corresponding deflection Δ in the load plane and the sideways deflection s perpendicular to the load plane are obtained by resolution, giving:

$$\Delta = (\Delta_{P_1}\cos\theta)\cos\theta + (\Delta_{P_2}\sin\theta)\sin\theta$$
$$= \Delta_{P_1}\cos^2\theta + \Delta_{P_2}\sin^2\theta,$$

and

$$s = (\Delta_{P_1}\cos\theta)\sin\theta - (\Delta_{P_2}\sin\theta)\cos\theta$$
$$= (\Delta_{P_1} - \Delta_{P_2})\sin\theta\cos\theta.$$

These expressions may be rewritten:

$$\Delta = \tfrac{1}{2}(\Delta_{P_1} + \Delta_{P_2}) + \tfrac{1}{2}(\Delta_{P_1} - \Delta_{P_2})\cos 2\theta$$

and

$$s = \tfrac{1}{2}(\Delta_{P_1} - \Delta_{P_2})\sin 2\theta,$$

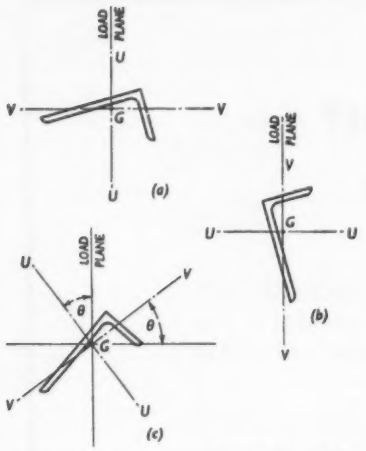


Figure 1. Uniform beam with unequal angle section.

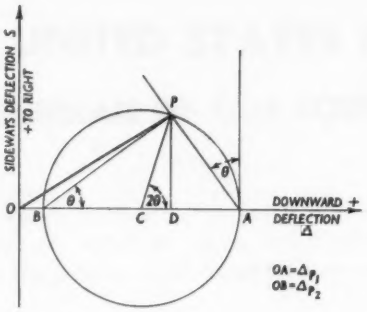


Figure 2. Mohr deflection circle.

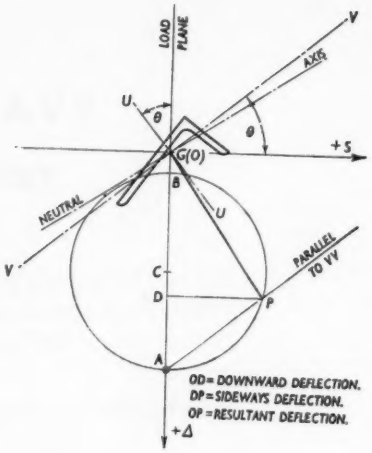


Figure 3. Circle oriented to show true directions.

which are typical Mohr circle equations and give a Mohr deflection circle, as shown in Figure 2, the sideways deflection s being plotted against the downward deflection Δ for revolution of the beam relative to the loading. The circle is constructed by computing Δ_{P_1} and Δ_{P_2}, plotting them as OA and OB, bisecting AB at C and drawing the circle with center C and radius CA. Any point P on the circle, such that angle PCA is 2θ, has coordinates giving the downward and sideways deflections when the principal axes are inclined at angle θ as in Figure 1 (*c*), since

$$\begin{aligned} OD &= OC+CD \\ &= OC+CP\cos 2\theta \\ &= \tfrac{1}{2}(OA+OB)+\tfrac{1}{2}(OA-OB)\cos 2\theta \\ &= \tfrac{1}{2}(\Delta_{P_1}+\Delta_{P_2})+\tfrac{1}{2}(\Delta_{P_1}-\Delta_{P_2})\cos 2\theta \\ &= \Delta \end{aligned}$$

and

$$\begin{aligned} PD &= CP\sin 2\theta \\ &= \tfrac{1}{2}(\Delta_{P_1}-\Delta_{P_2})\sin 2\theta \\ &= s. \end{aligned}$$

OP therefore gives the resultant deflection δ and angle AOP is its inclination to the load plane.

POSITIONING OF CIRCLE

The most convenient way of using the deflection circle is to draw it oriented as in Figure 3, using the centroid of the section as the origin and the trace of the load plane as the Δ axis, the positive direction being downwards. With this arrangement the co-ordinates show the deflections in their actual directions and OP is, to scale, the actual displacement of the centroid. Incidentally, this locates the neutral axis which is perpendicular to OP. Figure 4 shows a case where the principal deflections are upwards, the circle therefore lying above the centroid.

USE OF POLES

Since the deflection circle has been derived by considering different positions of a rotating beam, it does not have the usual kind of axis pole (Reference 1). Instead, every point on the circle becomes a pole for the rotation of a corresponding axis of the section. Thus, with the orientation of Figure 3, A is the pole for the rotation of axis VV, meaning that a line through A parallel to VV cuts the circle at the point P whose co-ordinates give the deflection components Δ and s for this position of VV. Similarly, B is the pole for axis UU. Only one pole is necessary to locate P, pole A being used in Figures 3 and 4.

USES OF DEFLECTION CIRCLE

As well as the determination of deflection for a particular orientation of the section, as in Figures 3 and 4, the circle is also useful for showing directly the necessary positions of the section to give particular deflection conditions. For example, Figure 5 shows that the principal axes must be at 45 degrees to the loading to give maximum sideways deflection s, while Figure 6 shows the position of the principal axes for the maximum leftward obliquity of the deflection to the load plane, OP being then tangential to the circle. The circle also demonstrates that the principal deflections are the maximum and minimum deflections as the section revolves relative to the loading.

USE OF AREA MOMENT CIRCLE FOR DEFLECTIONS

Since $\dfrac{\Delta_{P_1}}{\Delta_{P_2}} = \dfrac{I_u}{I_v}$ the Mohr area moment circle is

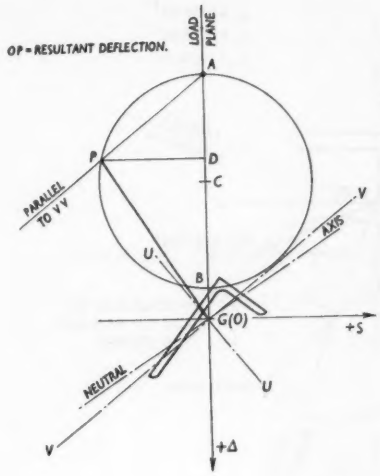


Figure 4. Deflection circle for upward principal deflections.

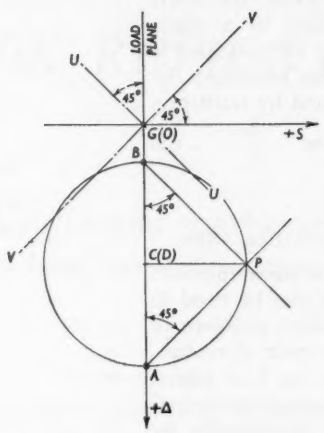


Figure 5. Position of principal axes for maximum sideways deflection.

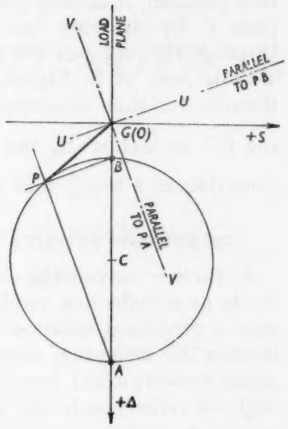
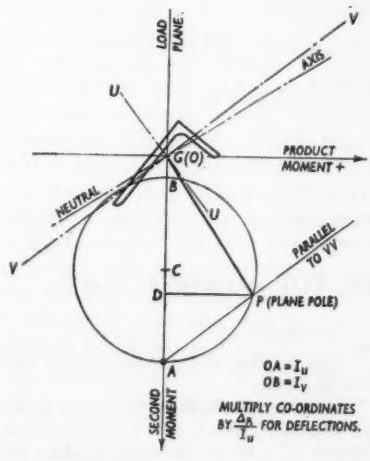


Figure 6. Position of principal axes for maxium obliquity of deflection to loading.

geometrically similar to the deflection circle and may therefore be used as such, as in Figure 7, the co-ordinates in inches[4] being multiplied by $\frac{\Delta_{P_1}}{I_u}$ to obtain the deflections. Since second moments are always positive, care must be taken to draw the circle below the centroid for downward principal deflections and above it for upward principal deflections. This use of the area moment circle saves time in plotting, as the circle can be drawn without computing deflections.

With this position of the area moment circle (that is, with the load plane trace used as the second moment axis), the point P giving the deflection coincides with the "plane pole" (Reference 1) of the area moment circle. This is the point diametrically opposite to the axis pole and is a pole through which a line parallel to any "plane of gyration" cuts the circle at a point giving the second moment for that plane. Thus, in Figure 7, PA parallel to plane VV cuts the circle at A where $OA=I_u$, which is the second moment for gyration in the direction of plane VV (i.e. about axis UU). Similarly, PB parallel to UU would cut at B where $OB=I_v$, which is the second moment for gyration in the direction of plane UU.



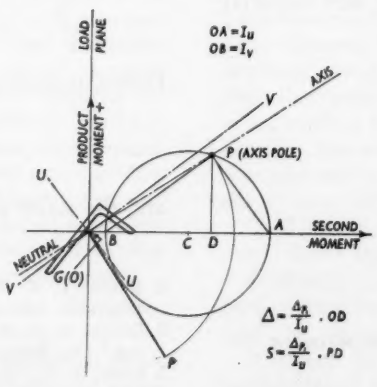


Figure 8. Normal position of area moment circle showing deflection values given by axis pole.

Figure 7. Use of area moment circle for deflection.

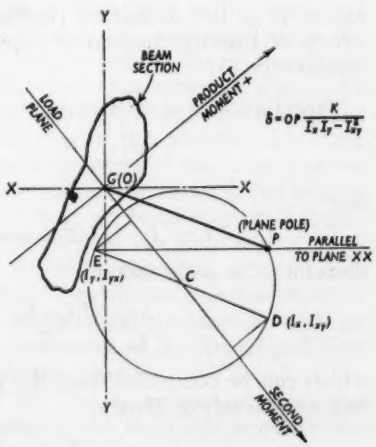


Figure 9. Area moment circle used to find deflection without reference to principal axes.

Hence, having drawn the area moment circle in this position, it is only necessary to locate the plane pole P by drawing one line parallel to a plane through the appropriate point (e.g. AP parallel to VV through A in Figure 7) and the resultant deflection δ is then immediately obtained by multiplying OP in inches^4 by the scale factor $\frac{\Delta_{P_1}}{I_u}$, the direction of δ being that of OP.

DEFLECTIONS WITHOUT USE OF PRINCIPAL AXES

A further advantage of using the area moment circle as a deflection circle is that it can be used to give a graphical solution of the general problem of finding the deflection relative to any pair of rectangular non-principal axes inclined to the load plane, without reference to the principal axes or principal second moments, a problem solved analytically by Levy (Reference 3). For this kind of problem it is convenient to draw the given axes XX, YY horizontally and vertically, as in Figure 9, and to draw the area moment circle, using the load plane as the second moment axis. The circle is drawn by plotting the points $D(I_x, I_{xy})$ *and* $E(I_y, I_{yx})$, the quantities I_x, I_y, I_{xy} being the given data for the section. The plane pole P is located by drawing either EP parallel to plane XX or else DP parallel to plane YY, the choice depending on which gives the better cut at P. OP then gives the direction of the resultant deflection δ. The value of δ could be obtained by multiplying OP by the scale factor $\frac{\Delta_{P_1}}{I_u}$ but this would involve reference to the principal axes. The scale factor can, however, be found from the given data as follows:

$$\Delta_{P_1} = \frac{K}{I_v}$$

where K is the deflection coefficient covering the effects of loading, method of support, and material (Reference 2).

Therefore, the scale factor

$$\frac{\Delta_{P_1}}{I_u} = \frac{K}{I_u I_v}$$

but

$$I_u I_v = I_x I_y - I_{xy}^2 \text{ (Reference 4)}$$

therefore the scale factor

$$\frac{\Delta_{P_1}}{I_u} = \frac{I_x I_y - I_{xy}^2}{K}$$

which can be computed from the given data for the beam and loading. Hence,

$$\delta = OP \cdot \frac{K}{I_x I_y - I_{xy}^2}$$

Figure 10 shows this construction used to solve the following problem: find the end deflection of an

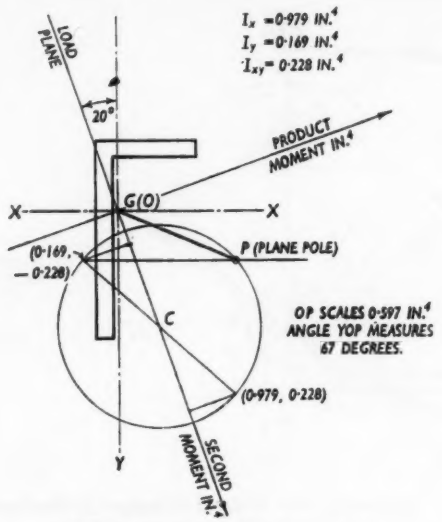


Figure 10. Numerical example.

angle section cantilever 2 feet long, carrying an end load of 15 pounds in a downward direction at 20 degrees to axis YY, as shown. Young's modulus is 10×10^6 pounds per square inch and the section particulars are $I_x = 0.979$ in^4, $I_y = 0.169$ in^4, $I_{xy} = 0.228$ in^4.

It is not really necessary to draw the section itself, but it is shown in Figure 10 for clarity. Having constructed the area moment circle and scaled OP (0.597 in^4), the calculations are as follows:

Deflection coefficient for a cantilever with end load is

$$K = \frac{Wl^3}{3E} = \frac{15 \times 24^3}{3 \times 10 \times 10^6} = 0.00691 \text{ in}^5$$

$$I_x I_y - I_{xy}^2 = 0.979 \times 0.169 - 0.228^2$$
$$= 0.166 - 0.052$$

Therefore the scale factor = 0.114 in.^{8}

$$\frac{K}{I_x I_y - I_{xy}^2} = \frac{0.00691}{0.114} = 0.0606 \text{ in}^{-3}.$$

Hence, deflection

$$\delta = OP \times 0.0606$$
$$= 0.597 \times 0.0606$$
$$= 0.0362 \text{ in.}$$

and the acute angle, YOP measures 67 degrees.

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1. Smith, T. F. W., "Uses of the Mohr Circle Pole," *The Engineer*, November 11, 1955.
2. Smith, T. F. W., "Graphical Method for Oblique Bending," *The Engineer*, July 25, 1958.
3. Levy, J. C., "Deflection of a Beam Referred to Any Set of Rectangular Centroidal Axes," *Journal of Applied Mechanics (Transactions of the American Society of Mechanical Engineers)*, Vol. 23, No. 3, page 464, September, 1956.
4. Salmon, E. H., *Materials and Structures*, Chapter VII, paragraph 85, page 168.

BOOK REVIEWS AND NOTICES

PROCEEDINGS OF THE SIXTH MIDWESTERN CONFERENCE ON FLUID MECHANICS

held at the University of Texas, Austin, Texas, September, 9-11, 1959.

30 Papers 465 Pages

Reviewed by
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Washington 7, D.C.

This volume, as the title indicates, is a compilation of the papers presented at the subject conference on fluid mechanics. Only a part of the presented papers have direct relation to Naval Engineering; most of them are devoted to problems related to Gas Dynamics, Compressible Boundary Layer Theory and Gasdynamic Heat Transfer. Only the papers dealing with subjects connected with Naval Engineering will be discussed in more detail.

J. P. Breslin and S. Tsakonas of Davidson Laboratory, Stevens Institute of Technology, presented a paper on "The Blade Frequency Velocity Field near an Operating Marine Propeller Due to Loading and Thickness Effects." Their investigation is limited to the case of a propeller operating in open water in an ideal liquid. The propeller is represented by the usual "lifting-line" model (bound, helical and hub vortices) and the blade sections by source-sink distributions. The authors develop analytical expressions for the various components of the transient velocity field, i.e., components due to bound and helical vortices and blade-thickness. The velocity distribution of a three-bladed propeller is computed and the results are presented in the form of tabulated functions and several graphs.

P. Kaplan and P. N. Hu, also of the Davidson Laboratory, present a method of calculating the hydrodynamic forces and moments acting on slender submerged bodies and body-appendage combinations moving oblique to the crests of regular waves. This paper presents the corrected version of a similar paper given by the authors at the third U.S. National Congress of Applied Mechanics in 1958. This time, the authors use corrected boundary conditions and also take into account the nonlinear terms in the pressure equation. This particular flow problem, which is time dependent and spatially nonuniform, is investigated by the authors utilizing two dimensional cross-flow techniques. By these means they accomplish a great simplification as compared with three-dimensional works by Havelock and Cummins. The equations are derived for the forces of a submerged body of revolution, a body of revolution with a pair of horizontal tail fins, and a body of revolution with a pair of vertical tail fins. It is shown that the force on the body cross-section is contributed by two components, the first might be identified as the time rate of change of fluid momentum associated with the particular section, and the second due to the spatial nonuniformity of the flow (the action of a pressure gradient across the body). It should be mentioned that due to the symmetry of the configuration there is no rolling moment in each of the above cases. Finally, the authors evaluate the forces and rolling moment acting on a body of revolution with a single vertical fin terminating at the stern end.

C. C. Mow and E. Saibel reported on gas lubricated slider bearings. They investigate the effect of the bearing speed, slope of the inclination, and aspect of bearing on the pressure developed and load carrying capacity of the bearing.

A paper by L. N. Tao is concerned with the mathematical solution of the Reynolds equation for a sector thrust bearing. The author presents an analytical solution and then establishes the bearing characteristics (i.e., load capacity, power loss, oil flow and side flow).

A paper of S. A. Berger and M. Holt is concerned

with the early growth of a spherical explosion in sea water, resulting from the detonation of an uncased spherical charge of PETN (pentaerythritol tetranitrate) at its center. The field of disturbance is found by integrating the equations of unsteady motion of an inviscid, compressible fluid with spherical symmetry, using a numerical method of characteristics.

J. M. Robertson presented a paper on turbulent plane-Couette flow between a fixed and moving wall. As most previous solutions have predicted, the velocity profile is characterized by a cone region in which the profile has a constant slope. Predictions are included for this slope and for the skin friction coefficient in terms of the mean-flow Reynolds number.

The results of a study of the diffusion of a circular submerged jet impinging normally on a smooth boundary were given by M. Poreh and J. E. Cermak. J. W. Delleur and D. S. McManus presented the results of an investigation of secondary flow in straight open channels.

L. M. Milne-Thomson presented a theoretical analysis on a special type of freestream-line flow. H. N. McManus, Jr., treated the problem of film characteristics and dimensions in an annular two-phase flow. V. D. Agosta and H. D. Baker presented a method of temperature determinations of Methane-air combustion products by velocity-of-sound measurements.

An electromechanical transducer for measuring dynamic pressures in fluids was discussed by D. A. Gilbrech; B. M. Leadon and E. R. Bartle presented a paper on the measurement of local skin friction by means of a surface probe in the case of low speed turbulent flow over a porous flat plate with mass injection.

In addition, papers on two-fluid flow (J. R. Banister), wind velocity profiles (I. A. Singer and G. S. Raynor), and flow through a porous medium (W. T. Guy, Jr., L. B. Lesem, and G. W. Crawford) were presented.

A brief mention of the papers concerned with gas dynamics and allied fields will now be made.

An account on recent progress in rarefied gas dynamic research was given by S. F. Shaaf. J. D. Cole and W. W. Royce discussed an approximate theory for the pressure distribution and wave drag of bodies of revolution at Mach number one, while M. Vinokur studied the hypersonic flow around bodies of revolution which are generated by conic sections.

A. G. Hammitt and S. Hight reported on scale effects in turbulent shock wave boundary layer interactions. M. Z. V. Krzywoblocki and J. T. Martin presented a paper on canonical forms, Beltrami flows and certain exact solutions in mangeto-gas-dynamics. S. I. Pai and A. I. Speth discussed the wave motions of small amplitude in radiation-electro-magneto-gas dynamics. G. S. S. Ludford and J. D. Murray presented the results of further studies on the flow of a conducting fluid past a magnetized sphere.

Heat transfer and boundary layer theory were treated in papers of W. Squire; J. T. C. Liu; J. P. Hartnett, E. R. G. Eckert, and R. Birkebak; S. T. Chu and J. D. Lee; Y. Nakagawa; N. M. Brown; and F. N. Edmonds, Jr.

Most of the papers present the results in tabulated form, suitable diagrams and graphs. Experimental techniques, description of the apparatus used and references are included. While the volume has been handsomely bound, no attempt was made to standardize the typing, lettering or symbols. This, together with the photo-offset reproduction, tends to make reading of the volume difficult.

One of the basic drawbacks of this "book" is the complete absence of discussions of the papers presented. Discussions of papers should have been the "raison d'être" of this conference, since most of the papers described were published, usually in a more detailed version, as separate reports and some were presented again at other meetings.

The contents of this volume clearly show the very diversified nature of the papers presented and, indeed, of modern fluid mechanics. In the opinion of the reviewers, the value of such a publication would be enhanced if a specific topic in fluid mechanics were selected for each conference. The conference proceedings would then include, in a single bound volume, papers and discussions on a topic of current importance and interest.

CHEMISTRY OF NUCLEAR POWER

by J. K. Dawson and G. Long
Published in 1959 by Philosophical Library, Inc.
15 Esat Fortieth Street, New York 16, N. Y.
208 pages of text and illustration plus eight plates
Price $10.00
Reviewed by J. B. Friauf
Electrical Branch, Bureau of Ships

Both authors are associated with the Reactor Chemistry Group of the Atomic Energy Research Establishment at Harwell, England. They state in the preface that they have not attempted to give a minutely detailed account of the chemistry of nuclear power but rather a broad picture of established practice and present lines of thought. In this they have been eminently successful.

A surprisingly large amount of information is packed into the confines of a rather small volume. Uranium is followed from its cradle in the rocks through its active life in reactor fuel elements to one or another of the graveyards devised for the disposition of radioactive fission products. Thorium for breeder reactors, and graphite and deuterium oxide for moderators also have their share of attention. There is a chapter on fission and fission products, one on the separation processes used to recover useful constitutents from irradiated fuel elements, and one on the handling of radioactive materials.

The chemical problems of nuclear power vary from one reactor type to another. In order to exhibit these problems in their proper settings, consideration is given to water-cooled, gas-cooled, and a number of miscellaneous reactor systems. Finally, at the end of the nuclear power process we wind up with the highly desirable power that the reactor systems were designed to produce, and the as yet highly undesirable radioactive fission products that the fission process produces along with the power. The disposition of radioactive wastes is a problem that will become even more pressing as the use of nuclear power increases. The authors devote one chapter to the disposition of radioactive wastes and a final chapter to possible ways of employing them in useful applications.

This is a well written book by men who have something to communicate and who know how to communicate. It should be useful collateral reading for students of nuclear engineering and for chemists, physicists, engineers, and metallurgists engaged in nuclear power work. For those with even a smattering of physics and chemistry, it can serve as an introduction to the production of power by nuclear fission.

NUCLEAR SHIP PROPULSION

by Holmes F. Crouch
Published in 1960 by Cornell Maritime Press
Cambridge, Maryland
347 pages of text and illustrations Price $10.00
Reviewed by
Joe W. Thornbury, CDR USN

The primary concern of this book is merchant ship nuclear propulsion, but the design and operating principles, the safety features required and the prospects for the future apply to warship propulsion as well. The author, through more than a decade of service as a U.S. Coast Guard officer and through having spent the past six years in nuclear engineering research, is eminently qualified to write on this subject.

The book is not intended to be a highly technical treatise on nuclear engineering, but rather to be a book readily understood by the marine engineer who seeks an appreciation and understanding of nuclear technology rather than a mastery of it. In this respect, it succeeds admirably. The nuclear physics and technical engineering details included are sufficient for the aims of the book but are not so highly complex and detailed as to be burdensome

to the non-nuclear engineer. Formulae have been kept to a minimum. The complete bibliography, and the footnote references thereto, can serve as a guide for further work for those interested in the more highly technical theoretics.

The author treats, in some detail, the commercial possibilities of nuclear propulsion and examines its advantages and disadvantages compared to fossil-fueled ships. With this as an introduction, he proceeds to cover the complete gamut of application of nuclear power including fuel calculations, shielding, various reactor types, safety, control, refueling, health physics and a look at the future of nuclear propulsion. While this is only a partial listing of subjects treated, it should suffice to give an idea of the broad coverage afforded.

NUCLEAR SHIP PROPULSION is interestingly written, timely and should prove a valuable reference for the marine engineer who is not a nuclear specialist.

ERRATA:

On page 183 of the February, 1960 issue of the JOURNAL, an error appeared in the title of the book reviewed. The corrected citation is as follows:

ELECTRIC MOTORS AND GENERATORS
by E. T. G. Emery, F. Harrabin, B. C. Lee,
Jr. R. Nixon, and E. T. A. Rapson
Published in 1959 by Philosophical Library,
15 East 40th St., New York 16, N.Y.
400 Illustrations 384 pages $12.00

BOOKS RECEIVED

"Sverdrup's Arctic Adventures" by T. C. Fairley, published by Longmans, Green and Co., Inc., 119 West 40th St., New York 18, New York. 305 pages, $6.00.

"Nuclear Power Plant" by E. O. Taylor, published by Philosophical Library, Inc., 15 East 40th St., New York 16, New York. 184 pages, $7.50.

"Kings Point, the United States Merchant Marine Academy," edited by L. J. Zaleski, published by Zale Publishing Co., 37 Menzel Avenue, Maplewood, New Jersey. A pictorial presentation of cadet life at the United States Merchant Marine Academy. 48 pages, $1.00.

"The Radiographic Image and Inhomogeneities in Welds," published by De Technische Uitgeverij H. Stam N. V. (The Technical Publishing Company H. Stam N. V.) Zijlwegl, P.O.B. 64, Haarlem, The Netherlands. A collection of radiographs, weld photographs, and a guide for their use, for correlation of welding inhomogeneities and their X-ray manifestations. 56 Cards in a steel filing box with a 92 page guide. 250 Dutch Guilders.

The French liner, *France*, is scheduled for launching this month, and is expected to enter transatlantic service in 1961. Under construction at St. Nazaire, the ship is being built on the ways on which the *Normandie* was built in 1935. With a length of 1035 feet, and a gross tonnage of between 55,000 and 60,000 tons, the ship is the largest passenger liner now under construction in the world. Her trial speed at her 160,000 designed shaft horsepower is estimated to be 34 knots.

—from THE SHIPBUILDER AND MARINE ENGINE-BUILDER

CHANGES IN MEMBERSHIP

CHANGES IN MEMBERSHIP

The Society announces with pleasure that the following have joined its ranks since the publication of the February 1960 issue of the JOURNAL.

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For safety, high-pressure, compressed-air and hydraulic systems must have proper maintenance and operation.

Two disastrous explosions occurred on aircraft carriers—one in October 1953; the other, in May 1954. In the earlier explosion, 37 persons were killed and 26 hospitalized. Material damage amounted to $660,000. In the later explosion, there were 102 deaths, 108 persons injured, and material damage was over $2 million. In both instances, the explosions, which occurred in the catapult systems, were initiated in the high-pressure portion of the hydro-pneumatic systems.

These incidents, as well as many others, have prompted much investigation into the nature and causes of explosions in compressed-air and hydraulic systems. As a result design changes, such as the introduction of fire-resistant hydraulic fluids and compressor lubricants, have been made. The studies, however, make it apparent that maximum safety can be attained only by proper operating and maintenance.

EXPLOSION DEVELOPMENT

. . The development of an explosion may be separated into two phases: (1) the ignition; and (2) the explosion. Ignition may result from several possible causes. The opening of a high-pressure air line to a low-pressure dead end can cause compression-ignition of combustible materials in the dead end. Sufficiently high temperatures for ignition can occur due to sudden compression of air in the dead-ended line. This phenomenon is often referred to as "compression-ignition," "diesel-ignition," or "dieselization."

Ignition may also be caused by oxidation of oil or other hydrocarbons in the piping at self-sustaining and accelerating rates due to heating and chemical action.

Ignition may possibly result from other causes, such as electrostatic discharge, compression of oil foam in a pump, external shock, and external fire.

Once ignition has occurred, an explosion will result if there is sufficient volume of flammable gaseous mixture resulting from vaporization of oil, or if the traveling flame of burning oil film accelerates into a shock wave. An oil film only a few thousandths of an inch thick may be enough to produce violent effects.

It is apparent from the foregoing, that prevention of such explosions can be accomplished by maintaining the compressed air and air piping free of oil and other combustible contaminants, and by preventing ignition from occurring by compression-ignition, high air temperature, or other causes.

PREVENTION MEASURES

- Inspect the interior of compressed air piping and components periodically. If oil or other combustibles are present in quantities amounting to more than a light film coating, the piping and components shall be cleaned until free of oil.
- Observe the operating procedures in the compressor instruction book and the "Bureau of Ships Technical Manual," chapter 49.
- Inspect and drain compressor coolers and separators as required, at 15-minute intervals in most cases.
- Frequently, inspect and drain piping system separators, filters, air receivers, piping low-point drain valves, and other components.
- Change air filter elements when necessary.
- Insure satisfactory operating condition of desiccant-type air dryers where installed. The desiccant will remove oil as well as water. However, when partially saturated with oil, the desiccant should be replaced since oil is not driven off when the desiccant is regenerated by heating.

SHORE SYSTEM CHARGING

When a compressed-air system is charged from a shore system, appropriate precautions should be taken to insure against contamination of the ship's air system. The shore system should be inpected for oil, water, and other contaminants, then blown down. Air should be delivered to the ship's system through suitable filters or separators.

High-pressure, compressed-air gages should not be tested in a deadweight tester that uses oil as a fluid. It is recommended that high-pressure air gages be marked "Use No Oil."

Compressors and compressed-air system piping should be monitored closely to make certain that no excessive temperatures will occur that could result in auto-ignition. Make certain that compressor high-temperature alarms and cutouts are operative.

Whenever a high-pressure air valve is opened to a downstream limited-volume or dead-end section, which is at reduced pressure, the valve should be cracked very slowly to prevent the possibility of compression-ignition. Pressure gage valves are a notable example of this type of hazard. If the gage has just been re-installed after inspection or testing, the pressure in the gage will be atmospheric. Compressed-air and hydropneumatic system valves should be analyzed to determine whether such a hazard exists. The marking of such dangerous valves is a highly desirable safety measure.

By frequent inspection and careful observance of safe operating and maintenance procedures, a high degree of safety in high-pressure, compressed-air and hydraulic systems can be assured.

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